SCHOOL OF
CIVIL ENGINEERING

INDIANA
DEPARTMENT OF HIGHWAYS

JOINT HIGHWAY RESEARCH PROJECT

INFORMATIONAL REPORT

JHRP-88-11

AN EVALUATION OF EFFECTS OF ROUTINE MAINTENANCE ON HIGHWAY PAVEMENT SURFACE CONDITION

Turki Al-Suleiman
Kumares C. Sinha

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TO: H. L. Michael, Director
Joint Highway Research Project

August 10, 1988

Report No.: JHRP-88-11

FROM: K. C. Sinha, Research Engineer
Joint Highway Research Project

File No.: 9-7-11

Attached is an informational report entitled "An Evaluation of Effects of Routine Maintenance on Highway Pavement Surface Condition." The research was conducted by T. I. Al-Suleiman under my direction for his doctoral program.

The report presents an evaluation of the effects of routine maintenance expenditure level on pavement surface condition and consequently on pavement service life. A conceptual framework for assessing the relationship between pavement age and routine maintenance was developed. Surface roughness was used as a measure of pavement condition and pavement age at terminal roughness value as a measure of pavement service life. The effects of traffic loading and regional factors were also considered in the framework.

T. I. Al-Suleiman was financially supported by Jordan University of Science and Technology. The IDOH data collected in several HPR projects were used in the study. It is felt that the research work will provide useful information to the IDOH and other highway agencies, particularly in the development of a pavement management system.

Respectfully submitted,

K. C. Sinha

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INFORMATION REPORT

AN EVALUATION OF EFFECTS OF ROUTINE MAINTENANCE ON HIGHWAY PAVEMENT SURFACE CONDITION

Report No.: JHRP-88-11

by

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ABSTRACT

This research was undertaken to analyze the effects of routine maintenance expenditure level on pavement surface condition and consequently on pavement service life. A conceptual framework for assessing the relationship between pavement age and routine maintenance expenditure level was developed. Surface roughness was used as a measure of pavement condition and pavement age at terminal roughness value was considered as a measure of pavement service life. The effects of traffic loading and regional factors were also considered in the framework.

The major work items within the scope of study included: (i) the development of mathematical models for routine maintenance and regional effects; (ii) the evaluation of the effects of pavement age and traffic loading on maintenance effectiveness; (iii) the examination of the relationship between routine maintenance and pavement service life; and (iv) the study of the impacts of

routine maintenance on timing of pavement resurfacing.

An integrated data base was developed from selected pavement sections from the Indiana state highway system including information on pavement routine maintenance, pavement roughness, and pavement characteristics. The data were collected based on pavement contract sections.

The results indicated that deterioration in pavement surface condition in the northern region was higher than that in the southern region. However, maintenance effectiveness was found, in general, higher in the northern region. Also, the effectiveness of patching and joint and crack sealing was found higher than that of patching alone. In addition, maintenance effectiveness for pavements that are in the middle range of their service life was found higher than that for pavements that are in the early phase of their service life.

Multiple regression was used to develop prediction models for the effects of routine maintenance expenditure level on pavement service life. The results of these models indicated that if patching and crack sealing expenditure level increases from low to high levels, resurfacing can be postponed 1 to 3.3 years for overlaid pavements and 1.6 to 8 years for flexible pavements.

CHAPTER 1

INTRODUCTION

1.1 Background Information

Several factors have contributed to the current highway infrastructure problem. Most of these highways were constructed in the late 1950s and 1960s, and they are now approaching the end of their design lives. Usage of the facilities has increased over the years due to population increase, urbanization, and general economic expansion. Consequently, in recent years, the major effort of state highway agencies has shifted from building new facilities to preserving and maintaining existing systems. Under a situation where available resources are limited and insufficient to meet total funding needs to match federal grants as well as to finance entirely state supported activities, effective highway management strategies are needed. Therefore, many states and even local agencies have already installed pavement management and maintenance management systems.

A pavement Management System (PMS), in its broadest sense, encompasses planning, design, construction, maintenance, rehabilitation, evaluation and research of pavements [1]. The function of a PMS is to improve the efficiency of decision-making, expand its scale, provide feedback on the consequences of decisions, facilitate the coordination of activities within the agency, and maintain the consistency of decisions taken at different management levels within the same organization.

Ideally, maintenance management is an integral part of PMS. The main purpose of the maintenance management component in a PMS is to monitor the costs associated with providing various levels of serviceability for any given situation. The costs are dependent on the type and level of maintenance activity, which can in turn affect pavement performance in terms of the rate of serviceability loss or the change in surface roughness for a pavement.

The objective of a Maintenance Management System (MMS) is to obtain an effective control and standardization of approach in the management of the resources such as labor, materials and equipment [2]. The emphasis of resource management is important, because if productivity of routine maintenance could be increased by one percent, a savings of over $150 million per year could be obtained on a national basis [7]. In recent years, the importance of relating

maintenance management to facility management has been recognized [88]. This recognition is due to the fact that routine maintenance greatly affects overall pavement performance. Another factor is that routine maintenance activities are not supported by federal assistance and they must be accomplished through state generated revenues. On the other hand, the cost of reconstruction or major maintenance may be met by federal grants of up to 90% of the overall expenditure. In order to develop a complete and comprehensive PMS, the role of routine maintenance should be appropriately considered.

Although pavement routine maintenance was emphasized in several studies [1, 3, 4, 5, 6] as a part of a PMS, it has not been effectively incorporated in pavement management system development. The reason for not explicitly considering routine maintenance in a PMS is primarily the existence of an organizational structure where routine maintenance decisions are separated from capital planning and program development process [88]. In addition, capital and routine maintenance activities have separate sources of financing.

There are many factors which make the task of managing routine maintenance activities difficult. First, it is difficult to quantify the benefit of changing existing practices or choice of treatment. Also, systematic data

collection is scarcely undertaken to evaluate the differences between alternative maintenance treatments for any given pavement defect in terms of overall cost-effectiveness. Another factor which makes effective routine maintenance management difficult is that the scope of operation involves many activities over thousands of miles of roads which must be maintained every year.

With the changing emphasis on facility management, efforts are being made to determine closely the effect of routine maintenance activities on pavement service life and hence the frequency and need for other major pavement repairs. Studies [8,9,10] have demonstrated that there exists a trade-off between the level of sealing activity and the level of patching activity. An effective pre-winter sealing activity tends to reduce the amount of post-winter patching required. Also, resurfacing a highway section produces an immediate reduction in pavement routine maintenance. However, questions still exist about the effectiveness of various levels of pavement surface maintenance activities and the time period over which resurfacing may be postponed if appropriate levels of these maintenance activities were undertaken.

These earlier findings strengthened arguments that an effective pavement maintenance program can result in an increase in the service life and consequently the

resurfacing cycle of highway pavements. The basic concept and methodology presented in this study was originally developed to determine the appropriate interface between routine and major maintenance activities. It was felt that the success of this interface would depend on the development of Routine Maintenance Management (RMM) data base that can be used to analyze the effect of various routine maintenance activities on pavement service life.

1.2 Purpose and Scope of Research

The scope of the research included the analysis of various levels of routine maintenance, represented by levels of expenditure, on pavement surface condition and consequently on pavement service life. To accomplish the basic goal, a conceptual framework for assessing routine maintenance effects was developed. The effects of pavement age, traffic loading, and regional factors on highway pavements were considered in the process of developing this framework.

Since pavement maintenance expenditures represent the largest portion of roadway maintenance, routine maintenance effectiveness was considered one of the main research areas in the Strategic Highway Research Program (SHRP) research plans [11]. SHRP is a highly focused, specially funded 5-

year research effort investigating different critical areas of highway research. Maintenance effectiveness is defined in SHRP as the degree to which a treatment prevents or retards the pavement deterioration process.

In the development of the conceptual framework, suitability of using surface roughness as a measure of pavement condition and pavement age as a measure of pavement service life was considered. Consequently, a relationship between pavement age and level of routine maintenance was developed.

Figure 1.1 shows the major work items within the scope of the present study. These work items include (i) the development of mathematical models for routine maintenance and regional effects; (ii) the evaluation of the effects of pavement age and traffic loading on maintenance effectiveness; (iii) the examination of the relationship between routine maintenance and pavement service life, and (iv) the study of the impacts of routine maintenance on timing of pavement resurfacing.

In order to accomplish the tasks, a data base for pavement routine maintenance, pavement condition and pavement characteristics of a selected sections of Indiana highways was developed. Earlier studies recommended that maintenance activities be recorded in detail in smaller

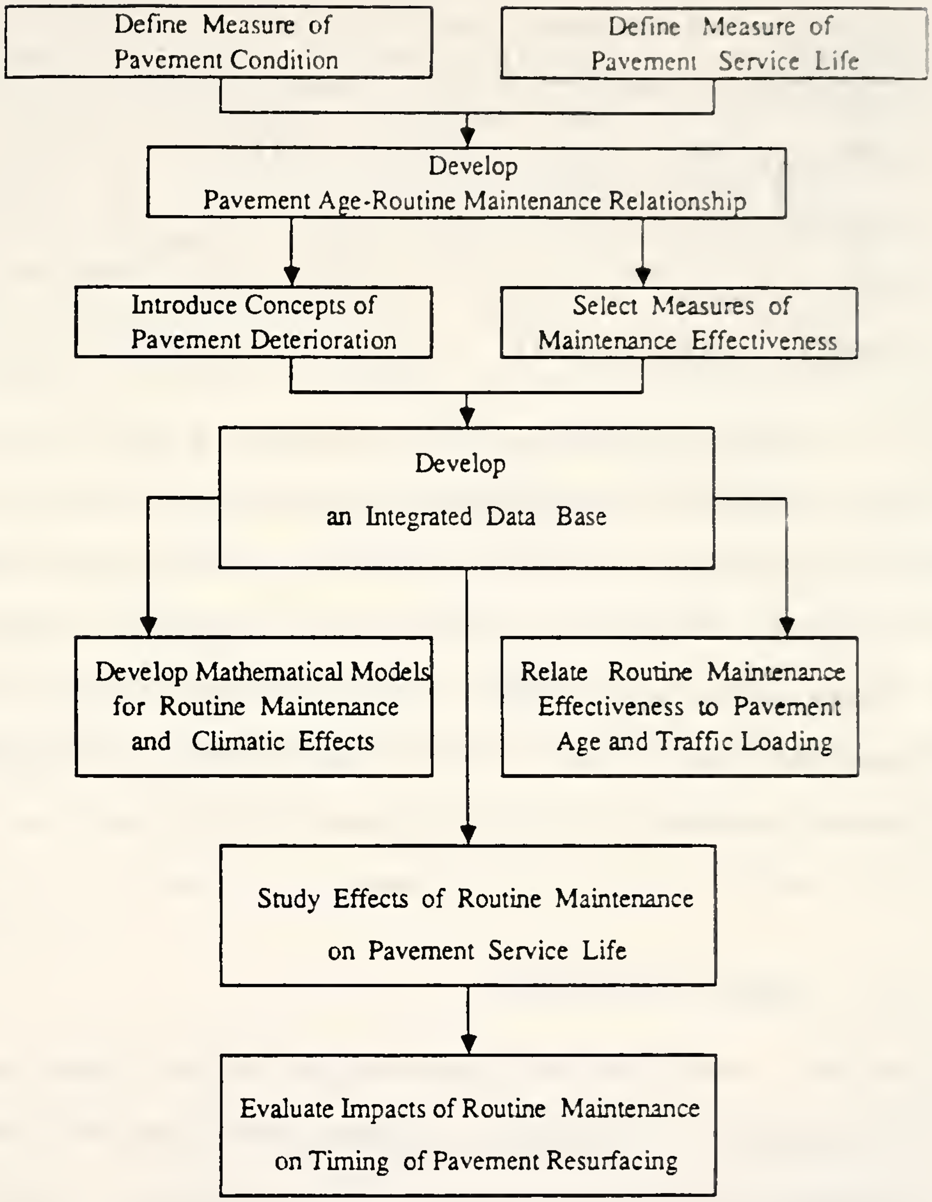


Figure 1.1 Major Work Items within Scope of Study.

pavement section units than the highway sections currently used [8,12]. Therefore, in the present study, the data base was developed based on pavement contract sections. Furthermore, because design, construction and maintenance criteria are different for different climatic regions, highway functional classes, and types of pavement, the analysis in this study was carried out separately for each region, highway class, and pavement type combination.

Based on findings of previous studies [8,12,13,14], two regions, two highway classes and three pavement types were considered. The two regions refer to northern and southern Indiana. The two highway classes include Interstate and Other State Highways (OSH). The three pavement types are flexible pavement, rigid pavement, and rigid pavement with bituminous overlay.

1.3 Report Organization

The report consists of eight chapters. Chapter 2 discusses the commonly employed disaggregate and aggregate pavement condition evaluation methods. An extensive literature review of current pavement performance models, effects of maintenance on pavement condition, and pavement management procedures in use by various highway agencies in the United States is presented. A literature review on

existing pavement condition evaluation methods in developing countries is also presented in the same chapter.

Chapter 3 focuses on the development of a conceptual basis for assessing routine maintenance effects. Suitability of using pavement surface roughness as a measure of pavement performance and pavement age as a measure of pavement service life is investigated. A relationship between pavement age and routine maintenance expenditure level is discussed. Measures of pavement deterioration and maintenance effectiveness are presented. The applicability of using the conceptual basis to study the effect of routine maintenance on user costs is also introduced in this chapter. Chapter 4 deals with the development of an integrated data base including pavement routine maintenance, pavement condition in terms of surface roughness, pavement characteristics, and other related information.

The results of applying the proposed conceptual framework to selected sections of the state highway system of Indiana are analyzed in Chapters 5, 6, and 7. Chapter 5 investigates the effects of routine maintenance expenditure level on rate of change in pavement roughness. In Chapter 6, the effects of pavement age and traffic loading on maintenance effectiveness are analyzed and evaluated. This

is followed by Chapter 7 which presents an analysis of the effects of routine maintenance expenditure level on pavement service life. Finally, Chapter 8 contains the summary of proposed approach and major findings of the study. Areas where further research is required are also indicated in this chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In general, there are two broad approaches used in the evaluation of highway pavement condition and its relation to maintenance and rehabilitation expenditures [12]. One is an aggregated approach based on overall pavement performance and related expenditures. The other approach considers pavement performance and expenditure by estimating the extent and amount of individual pavement distresses.

The two approaches differ significantly in the way pavement condition is evaluated and the effect of maintenance and rehabilitation expenditures on pavement deterioration is considered. The use of the disaggregate approach requires detailed damage data for individual distress types. In contrast, the data required for the aggregate approach are much less and more readily available.

The aggregate and disaggregate pavement condition evaluation methods in the United States are discussed in this chapter. Pavement condition evaluation methods in developing countries are also presented.

2.2 Review of Disaggregate Pavement Condition Evaluation Methods

2.2.1 M.I.T. Pavement Life Cycle Cost Study (EAROMAR-2 System)

The Economic Analysis of Roadway Occupancy for Freeway Pavement Maintenance and Rehabilitation (EAROMAR) was developed during the early 1970's and published in 1974 by Butler [15]. The computer program, EAROMAR, permits an economic evaluation of premium pavements. A premium pavement is generally defined as a pavement requiring no major maintenance during its design life. The economic analysis is based on the conventional pavement design and traffic volume parameters specified by the user of the program. The prediction of the amount of maintenance depends on pavement age only, which is one of the major criticisms of this program.

The EAROMAR system was updated to become EAROMAR Version 2 (EAROMAR-2) by Markow [16]. The EAROMAR-2 system is a simulation model to predict pavement performance, and

maintenance and rehabilitation costs. A series of pavement distress models was employed by this system to predict pavement damage. Pavement performance was represented by a Present Serviceability Index (PSI) which was estimated from the damage components. Maintenance policies considered were used to estimate maintenance work load requirements by activity. Maintenance costs were then estimated after applying relevant scheduling and management decisions. Figure 2.1 shows a flow chart to simulate maintenance operation in EAROMAR-2.

An extensive amount of data was required as input to the simulation such as route characteristics, traffic demand, environmental conditions, maintenance policies, pavement characteristics, and user consequences. The simulation model was used by Wong and Markow [17] to study the allocation of life-cycle pavement costs, including routine maintenance and rehabilitation, but, excluding initial construction and reconstruction. This work was an extension of the Federal Cost Allocation Study [18]. The EAROMAR-2 has the advantage of being accurate and useful at a project level. However, the extensive amount of data required limits its applicability at a network level.

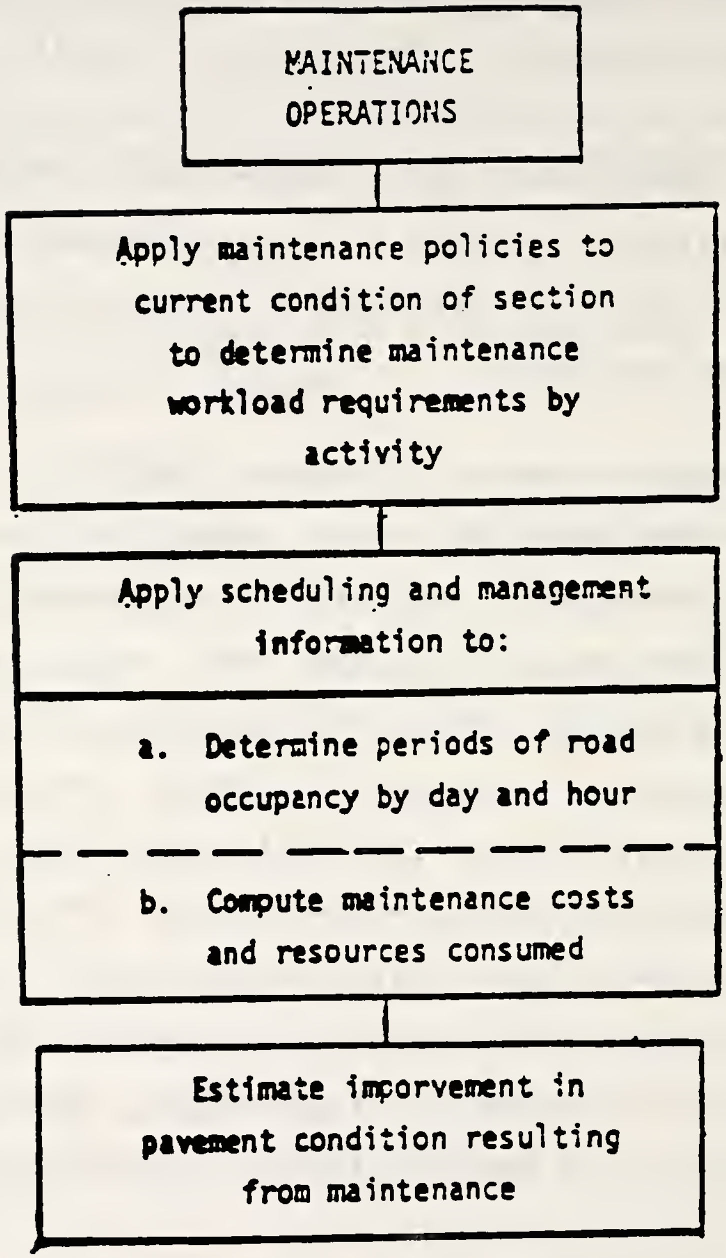


Figure 2.1 Simulation Flow Chart of EAROMAR-2 Maintenance Operations. [16]

2.2.2 1985 Austin Research Engineers (ARE) Study

In 1985, Austin Research Engineers (ARE) [19] developed models to predict pavement distress, damage, and serviceability as a function of pavement design and material characteristics, traffic, environmental factors, and maintenance and rehabilitation treatments. Figure 2.2 shows the analysis procedure of the approach. Distresses and performance measures as well as maintenance and rehabilitation activities were first selected for modeling. Then, a data base was developed from existing data sources such as construction and maintenance records. Finally, pavement serviceability and distress prediction models were developed by using regression analysis.

Maintenance and rehabilitation activities were classified according to frequency and impact in ARE models. Frequency was defined as the number of applications of an activity during the analysis period. Impact was measured as a change in pavement condition and strength. The pavement condition after maintenance and rehabilitation is updated in ARE methodology using the formulation below:

$$(\text{Condition})_{J+1} = (\text{Condition})_{J} + \Delta(\text{Condition}) \qquad (2.1)$$

where,

Δ = change in condition due to maintenance and

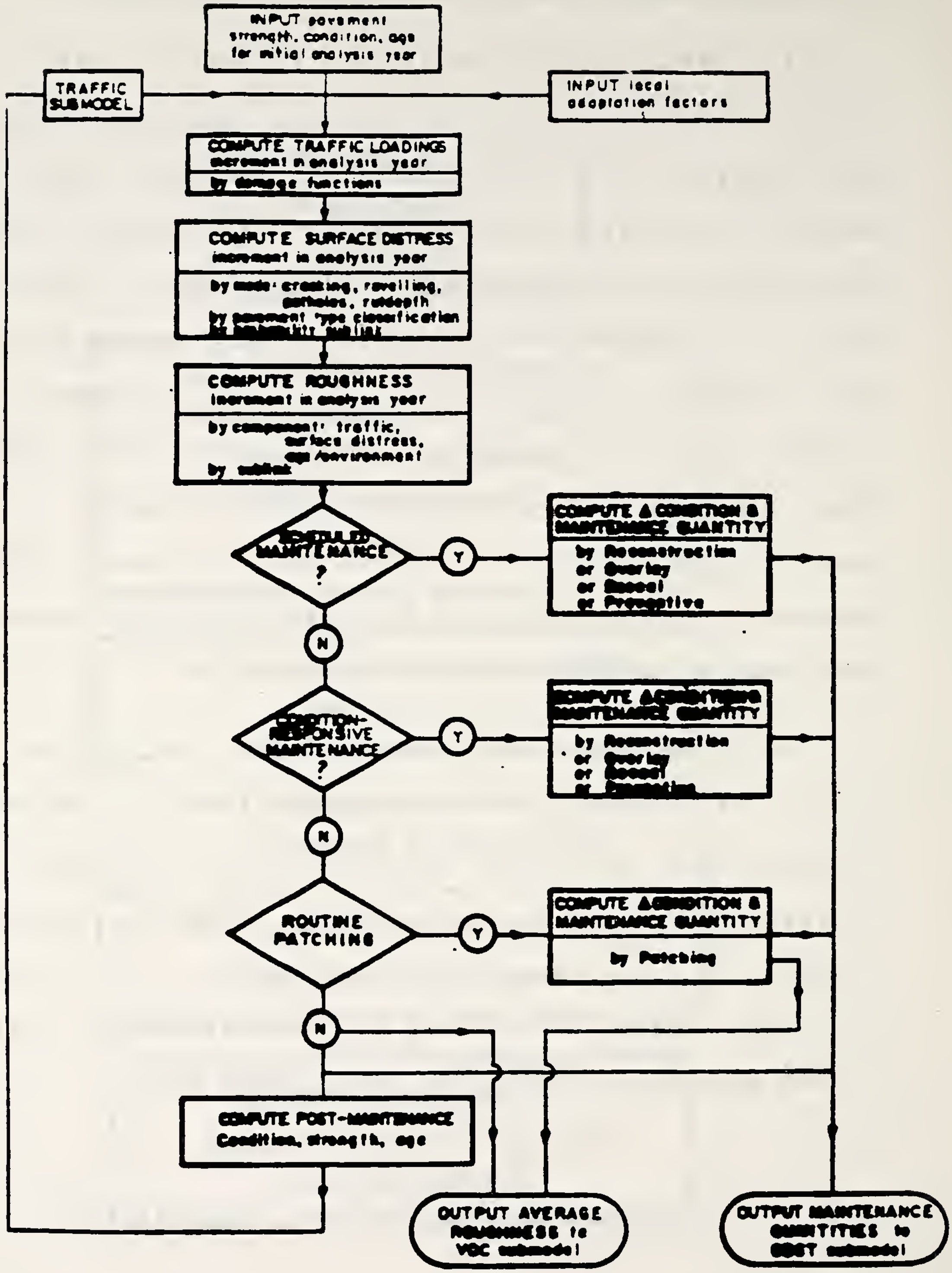


Figure 2.2 Analysis Procedure of the ARE Study. [19]

rehabilitation

J = analysis year

Extent and severity of cracking, rutting, potholes, roughness, and raveling were used as a measure of pavement condition. Maintenance was specified as either scheduled, condition responsive, or preventive treatments. The ARE methodology is available only to predict flexible pavement distresses. Another limitation is that a considerable amount of data is required to estimate the maintenance and rehabilitation expenditure. Pavement with no construction and maintenance history cannot be modeled effectively using these models because pavements are categorized by surface and base type. However, the ARE methodology can be effectively used to study the impact of different maintenance and rehabilitation policies on pavement deterioration rates. The EAROMAR-2 system and ARE methodology are very similar, but EAROMAR-2 needs more data to be applied.

2.2.3 PAVER Pavement Management System

The U.S. Army Corps of Engineers [20] developed a pavement management system (PAVER) for use by military installations, cities and counties. The management system used in PAVER requires the demarcation of the pavement

network into manageable sections for inspection and estimation of maintenance and rehabilitation needs. The pavement condition index (PCI) on a scale of (0-100) is an aggregate measure estimated from a combination of disaggregately measured distress types, severity, and extent obtained during inspection. The procedure for estimating the PCI is graphically shown in Figure 2.3.

The PAVER system includes a condition history which is obtained from several pavement inspections. Future PCI is predicted from condition history by linear interpolation. The relevant maintenance and rehabilitation activities are selected depending on the respective percentage of deterioration attributed to each cause. The level of maintenance and rehabilitation required is estimated by investigating the variation of PCI within the pavement section under consideration. The PAVER system includes management procedures that can be used for economic analysis, priority setting, and consequently budget planning.

The PAVER system, as demonstrated by Uzarski [21], can be used at the network level by minimizing inspection hours. However, this procedure is expensive and cannot be used effectively for network level decisions because it is still site specific. The PAVER system considers pavement roughness in a subjective manner. It is limited when

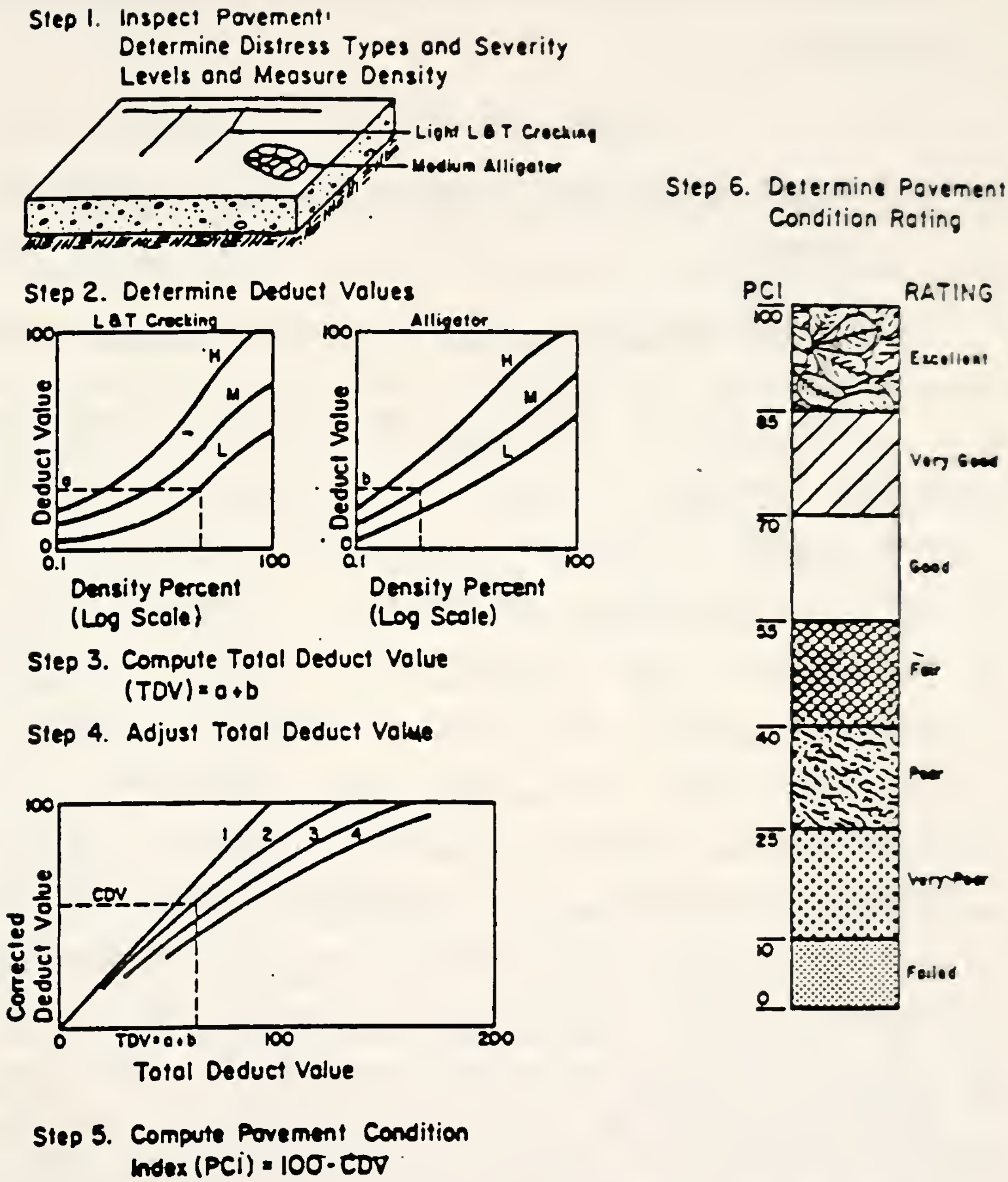


Figure 2.3 Steps for Calculating the Pavement Condition Index (PCI). [20]

evaluating various levels of routine maintenance such as patching and sealing and their relative effects on pavement condition.

2.3 Review of Aggregate Pavement Condition Evaluation Methods

2.3.1 Purdue Maintenance and Pavement Performance Studies

The state of Indiana has an extensive pavement network which consists of approximately 91,700 miles of highways and streets of which about 30,000 miles correspond to the federal-aid primary and secondary system [22]. The total mileage under the jurisdiction of the Indiana Department of Highways (IDOH) is about 11,000 miles consisting of Interstate and other high type facilities. Routine maintenance represents a large percentage of the total highway expenditure in the Indiana Department of Highways (IDOH). This level of routine maintenance expenditure is typical of other state highway departments in the U.S. or regional or national highway authorities in most countries in Europe [23]. The IDOH has developed a MMS for the programming, scheduling, and monitoring of routine maintenance operations. Several studies have been conducted at Purdue University through the Joint Highway Research Project (JHRP) to improve the effectiveness and efficiency

of the existing MMS. These studies are discussed in the sections below.

2.3.1.1 Pavement Maintenance Cost Models

Sharaf and Sinha [9], in a study of highway maintenance costs, examined the relationship between level of routine maintenance and pavement characteristics. A comprehensive data base was developed combining pavement maintenance information, climatic zone, traffic data, and pavement characteristics. The data base was used along with other results to develop routine maintenance cost prediction models. These models estimate the total annual maintenance costs per lane-mile as a function of accumulated traffic for flexible pavements and as a function of age and accumulated traffic for rigid pavements. Furthermore, separate models were developed to estimate future patching and sealing costs. The prediction models for sealing cost showed a strong relationship to traffic level, while patching models indicated that the extent of patching in a year would depend not only on the traffic level, but also on the level of sealing activity undertaken in the same fiscal year.

The models developed by Sharaf and Sinha [9] did not relate maintenance cost to pavement condition. Also, the

results were not directly related to the need for resurfacing. However, these aggregate models could be used to estimate total maintenance cost and expenditures for particular maintenance activities.

2.3.1.2 <u>Routine Maintenance and Pavement Performance Relationship Model</u>

Fwa and Sinha [12] developed an aggregate damage approach to relate pavement performance to routine maintenance expenditure. This approach was based on the serviceability performance concepts of the AASHO road test of the early 1960s. New concepts were introduced to represent pavement performance and maintenance effectiveness. These concepts included the definition of PSI-ESAL loss as an aggregate representation of pavement damage. Also, the concept of the zero-maintenance curve was developed to examine the effect of routine maintenance.

The concepts in this approach were originally developed for Indiana highway cost allocation study [24] for allocating pavement maintenance and rehabilitation costs. The major items within the scope of this aggregate approach are summarized in Figure 2.4. The approach was based on the use of readily available pavement roughness data rather than individual distress data to predict

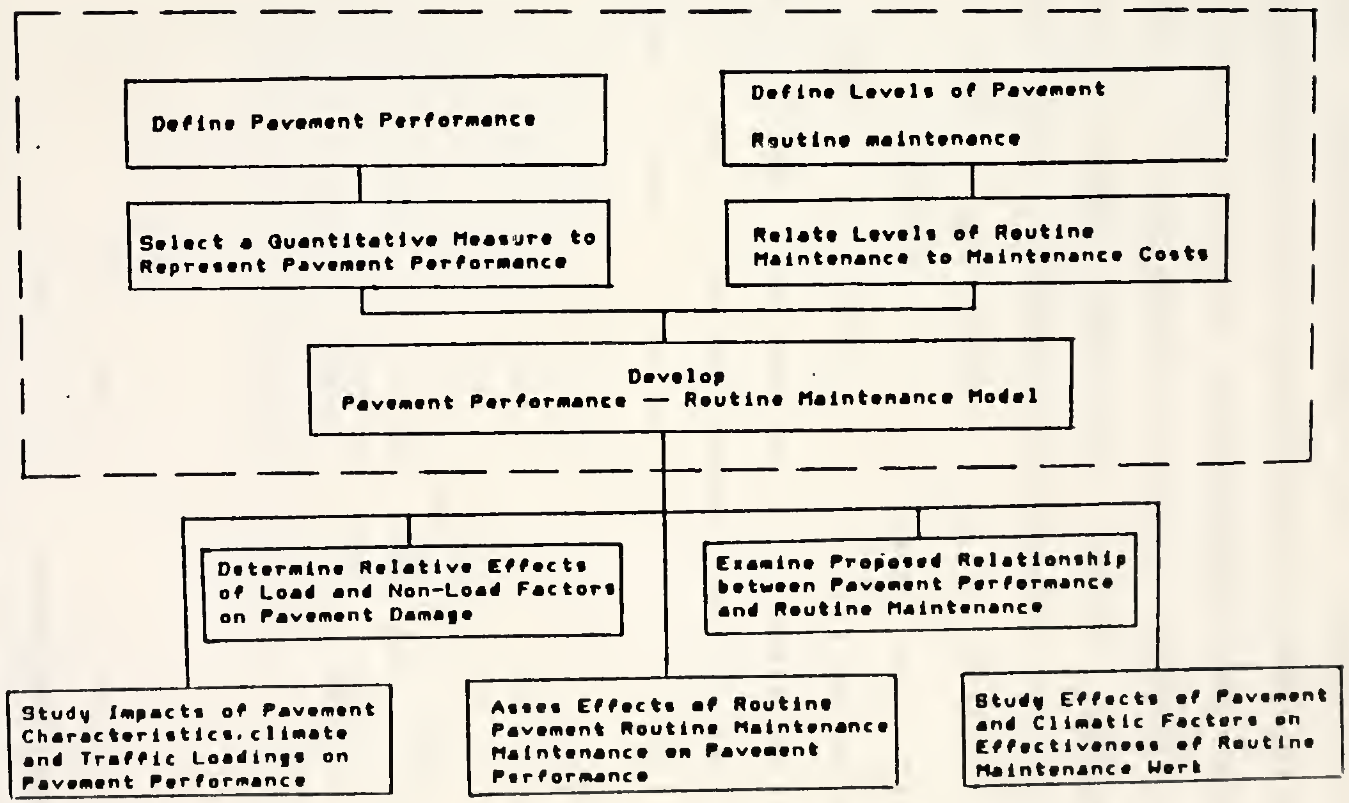


Figure 2.4 Major Work Items within Scope of Study. [12]

pavement performance. The analysis included (i) the examination of the relationship between pavement performance and routine maintenance; (ii) the evaluation of the effects of routine maintenance on pavement performance; and (iii) the study of the effects of pavement, climatic, and environmental factors on effectiveness of pavement routine maintenance work. This approach considered mainly the effect of total routine pavement maintenance cost, rather than the expenditure of individual routine maintenance activities, such as patching and sealing, on pavement performance. A linear regression relationship was developed using a limited amount of data. It was indicated that in order to provide the necessary data for establishing the desired relationship, a detailed record of maintenance activities and maintenance costs must be available. It should also be noted that in earlier studies [9,12], routine maintenance information was recorded on the basis of a highway section. A highway section is defined as the portion of a specific highway that lies between county limits.

2.3.1.3 Other Studies

Other studies have been conducted at Purdue University to develop procedures for assessing and allocating maintenance and rehabilitation funds to existing pavements

within the state of Indiana. Colucci-Rios and Sinha [25] developed procedures for establishing resurfacing priorities under limited financial resources. Two optimization models and a graphical approach were proposed. Pavement condition information, roughness number, traffic and pavement age were the primary factors considered in the optimization. Pavement contract section was used as the decision variable in the analysis procedure. The criterion used to select a resurfacing strategy was based primarily on average daily traffic (ADT) rather than equivalent single axle load (ESAL) or percent of trucks. Also, routine maintenance considerations were not dealt with in detail.

Montenegro and Sinha [26] introduced a procedure for the assessment of routine maintenance needs based on unit foremen's evaluation of highway deficiencies. Both subjective and objective data were used together with estimation of expected workload by unit foremen. Regression models were developed to predict the maintenance workload. These models can be improved by further training of the foremen in the recognition of highway defects. Feighan et al. [27] followed with a complementary study which estimated the unit costs and service lives for various routine maintenance activities. In both studies [26,27], the necessary information was obtained through a survey,

based on stratified random sampling, of maintenance personnel at the subdistrict level within Indiana. Effects of traffic and regional factors were not directly considered in these studies.

2.3.2 Demand Responsive Approach to Highway Maintenance and Rehabilitation

The demand responsive approach to maintenance and rehabilitation was developed by Geikie and Markow [28]. The objective of the study was based upon fundamental knowledge of how a pavement behaves, not only to predict pavement condition over time, but also to understand how this condition is affected by maintenance and rehabilitation policies. Maintenance and rehabilitation were viewed as responses to the demand for repair of the facility. The demand for maintenance or rehabilitation was predicted based on pavement design characteristics, traffic loadings, surrounding environments, and maintenance policies. The approach required the following general considerations:

i. Prediction of future pavement needs could not be obtained from historical data. So these predictions were based upon surface condition deficiencies caused by traffic, environment, and pavement age.

ii. Maintenance models had to be sensitive to changes in maintenance policies and extent of maintenance performed. Therefore, unambiguous statements of maintenance and rehabilitation policies were defined.

iii. A relationship was established between the current pavement condition and the associated maintenance and rehabilitation expenditures, so that an economic and engineering analysis could be carried out to examine the impacts of different policies.

Elements of the demand responsive methodology are summarized in Figure 2.5. The performance of pavement in this approach was measured as an aggregate index (PCI) which is a combination of various distress levels and severities.

The demand responsive approach concepts were implemented by using simulation models and optimization procedures. Humplick [29] developed simulation models to predict pavement expenditures in highway life cycle costing. The functional forms of these models were found linear for rehabilitation and non-linear for maintenance. Maintenance cost models were thus more sensitive to variation in unit costs than the rehabilitation models. Pavement performance prediction models were developed for flexible pavements. The models were found to be of similar

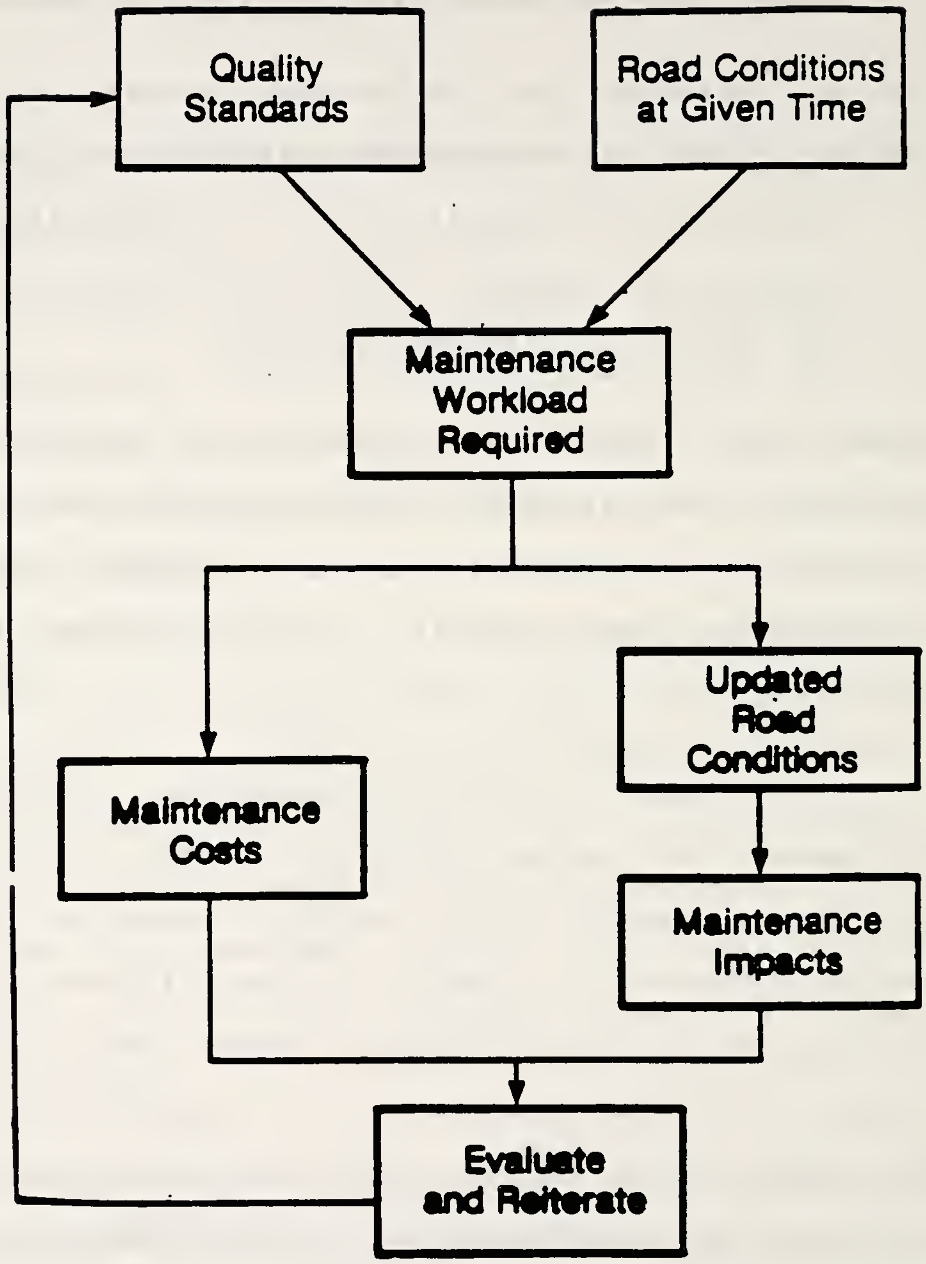


Figure 2.5 Demand Responsive Approach to Pavement Investment. [28]

functional forms for various maintenance activities considered in the study.

Balta and Markow [30] developed optimization technique to model both maintenance and rehabilitation investment decisions at the project level for a single highway pavements. Routine maintenance and rehabilitation activities were treated in separate models. Optimal dynamic control theory was applied to determine the optimal level of routine maintenance expenditures over time for a pavement. The control theory was also applied to determine the optimal timing of rehabilitation investment decisions.

One of the limitations of the demand responsive approach is that the simulation and optimization models were based on a limited data base. The analysis revealed that the form in which the data were collected was not useful for direct use in the modeling procedure. Also, the models were developed for only three maintenance activities. In addition, the study developed conceptual outlines rather than specific procedures.

2.4 Review of Pavement Condition Evaluation Methods in Developing Countries

2.4.1 Road Deterioration and Maintenance in Developing Countries

In the past two decades, there have been large increases in the length of road networks in developing countries to meet rapidly increasing traffic demands. The result today in many developing countries is a network of deteriorating roads, many of which are beyond the stage where routine maintenance can be effective. For example, Jordan annually spends about $250 million, 5% of its total annual budget, in an effort to rehabilitate and maintain its road network which is severely damaged as a result of heavy traffic loadings [31].

Based on information from recent field surveys conducted by the World Bank [32,33,34], more than 25 percent of the paved roads in 60 developing countries are in poor condition and need rehabilitation or reconstruction. In addition, 42 percent of these paved roads are in fair condition and need major maintenance or strengthening. Most of the developing countries which currently have relatively good road conditions are located within Sub-Saharan Africa, Latin America, and East Asia regions. This is because of recent large additions to their networks and the fact that such roads have not yet reached

the end of their design lives [34]. However, the routine and periodic maintenance needed to prevent the parts of the network in good and fair condition from deteriorating further during the 1986-1990 is about $4.6 billion per year [33].

Although there are still some technical problems in developing countries to be solved in the area of road maintenance, most of the problems that exist are managerial rather than technical [35]. The reason behind that is the slow development of maintenance management techniques. Most maintenance organizations in the developing countries have enough labor forces which are unproductive because of poor management, lack of training, and lack of resources to carry out maintenance works. This problem has been compounded because of poor attitudes to maintenance which are frequently shown by politicians, planners, and engineers who often prefer to be associated with construction projects rather than maintenance works [36].

As a result of the problems mentioned above, the World Bank, in 1971, initiated what ultimately became a major program of collaborative research involving institutions in several countries to develop a new quantitative basis for decision making in the highway sector. Basic relationships for pavement deteriorations and maintenance effects have been established first in Kenya and later on a much larger

scale in Brazil [37,38]. These relationships have in turn been incorporated in the World Bank's Highway Design and Maintenance Standards Study (HDM) [39,40,41,42]. Among the most important advances from this research program was the development of the International Road Roughness Index (IRI) [43]. The major elements of this research program are discussed in the sections below.

2.4.2 Kenya and Brazil Models

The pavement performance studies in Kenya [37] and Brazil [38] had a common objective, namely to develop models to describe the pavement performance and deterioration as functions of regional design and constructions standards, environmental factors, traffic loading and maintenance policies. In the Kenyan study, most of the pavements were of cement-stabilized base. The data range was limited and the resulting relationships did not work well, particularly for thin pavements. In the Brazil study, the number of sections and pavement types were more than double that of Kenya. In addition, the range of pavement strength covered virtually the whole range currently used in developing countries. The ranges of pavement age, roughness, and observed change in roughness were double those of Kenya. The climates of the two study regions were also different.

A major principle of both studies was to study pavement performance under normal operating conditions, rather than through experimental testing. Both studies assessed the same type of parameters such as cracking, potholing effects, rut depth, roughness, and deflection. Strong relationships have been developed from the Brazil study for pavements under normal maintenance. The effects of maintenance on the rate of pavement deterioration were not well quantified. In the Brazil study, the major differences in behavior before and after maintenance were in cracking, but there were no significant differences in roughness progression. In the Kenya study, strong reductions in the progression of roughness following multiple reseal applications have been shown. The results of both studies have been used in the development of the HDM to predict pavement deterioration under normal maintenance policies.

2.4.3 International Road Roughness Experiment

The International Road Roughness Experiment (IRRE) was organized in Brazil in 1982 with the participation of leading research institutes from six countries and the World Bank [43]. As a result of the IRRE, roughness has been defined in an International Roughness Index (IRI). The IRI is a time-stable, transferable, and absolute measure of

the road profile in a wheel track. It is expressed in units of meter/kilometer which represent the effect of that profile on the axle-body motion of a moving vehicle, idealized in a quarter-car simulation. The IRI is similar in concept to the Quarter-car Index (QI) scale developed in the Brazil study [38]. A summary description of the IRI scale is shown in Figure 2.6.

The IRI was used as a primary reference scale in the development of the HDM. The roughness data on which all the model relationships in HDM were based are the calibrated Maysmeter estimates of a reference QI of profile measured by a dynamic profilometer. For that reason, the IRRE developed conversion relationships between the IRI and other common roughness scales such as QI and Bump Inegrator (BI) trailer of Transport and Road Research Laboratory in the United Kingdom. The QI and BI are expressed in the units of counts/kilometer and millimeter/kilometer, respectively.

2.4.4 The World Bank's Highway Design and Maintenance Standards Study (HDM)

The Highway Design and Maintenance Standards Study (HDM) was undertaken by the World Bank over a period of 15 years. The HDM focused on the rigorous empirical

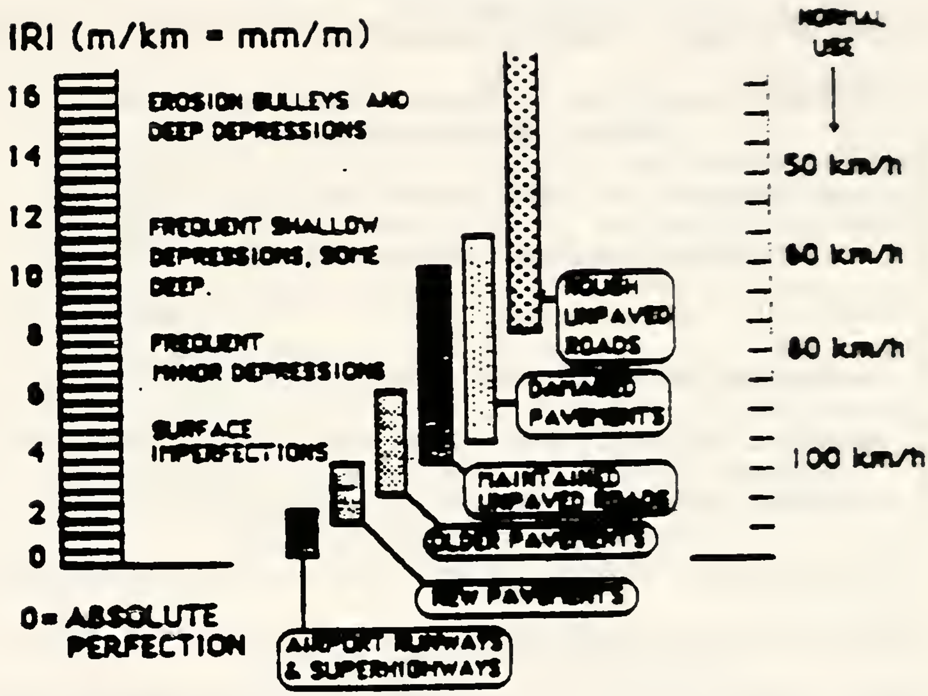


Figure 2.6 The International Roughness Index (IRI) Scale of Road Roughness. [43]

quantification of the cost tradeoffs among road construction, maintenance, vehicle operating costs, and the development of planning models (HDM-III), incorporating total life-cycle cost simulation as a basis for highway decision making. The HDM theoretical concepts and statistical estimation along with the planning models (HDM-III) have been published in four volumes [39,40,41,42].

The primary data base utilized in the HDM study was that of the Brazil study [38]. Other empirical studies conducted in different countries and climates, particularly two studies in Kenya, were used to test the validity of the models developed from the Brazil data base and to make preliminary evaluations of the effects of environment and materials across regions. The IRI measure of road roughness was used in order to facilitate the worldwide interchange and transferability of results. The results of the HDM study included five submodels as shown in Figure 2.7. The literature in the present study focused on the road deterioration and maintenance submodel.

The road deterioration and maintenance submodel analyzed the combined effects of traffic, environment, age, and maintenance policy on pavement condition and consequently on vehicle operating costs. Road deterioration was predicted through different separate distress modes

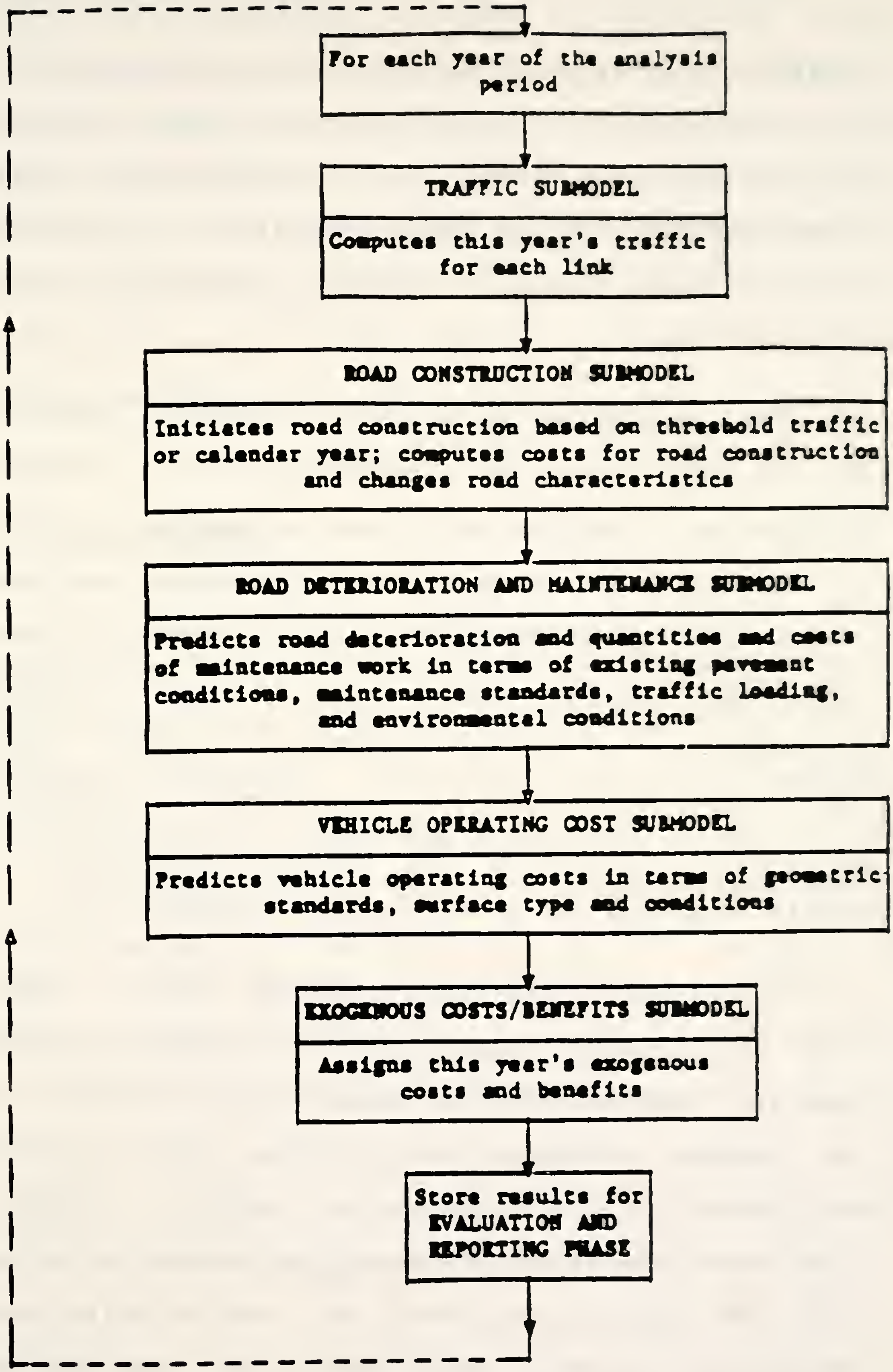


Figure 2.7 Submodels of the HDM Study. [42]

such as cracking, raveling, potholes, rut depth and roughness progression. Road deterioration was computed as the incremental change in pavement condition during each analysis year. The effects of five maintenance categories were considered in the development of these relationships: reconstruction, overlay, resealing, preventive treatment, and patching.

The road deterioration and maintenance relationships in the HDM study were considered to be suitable for application in regions other than the original study base in central Brazil. However, some adjustments when applying these relationships elsewhere will be needed, because of differences in climate, certain materials and types of pavement, and construction techniques. In many instances, the collection of time-series data over a period of five years will be infeasible. So, the use of one-time cross-sectional data as an alternative was recommended.

One of the limitations of the HDM model is that the road deterioration and maintenance submodel was developed only for flexible pavements and did not include the effects of freezing climates. Also, among routine maintenance activities, only the effect of pothole patching was considered. The effect of preventive treatments such as fog seal and slurry seal were not statistically modeled. Therefore, tentative relationships have been incorporated

in the submodel based on an engineering evaluation.

The HDM model was employed by Bhandari et al. [44] to develop relationships between initial pavement design strength and subsequent maintenance and to study the effect of budget constraints on economic priorities. Many developing countries such as Ghana, Botswana, and Indonesia [45,46,47] used the HDM model to improve the existing pavement maintenance and management systems.

2.5 Review Summary

It was concluded from the literature review that the disaggregate approach to represent pavement performance has a sound theoretical basis, but requires extensive data on pavement distresses. The review of existing disaggregate pavement condition evaluation methods indicated that there are four major steps which are common to these methods. These steps are: (i) identification of the distress types which affect pavement condition; (ii) development of prediction models for each distress type; (iii) modeling the effect of maintenance and rehabilitation in correcting each distress type; and (iv) studying the behavior of the pavement distresses mechanisms after applying specific activities of maintenance and rehabilitation.

Due to the limitations of present day knowledge on pavement distresses and because pavement distress data are often unavailable or inaccurate, the disaggregate approach may not be appropriate for predicting the effects of pavement maintenance expenditures on pavement condition. Also, this approach is mainly useful at the project level and may not be necessary at the network level. The aggregate approach does not require as much data as the disaggregate approach and it is more feasible for network level prediction models.

The aggregate pavement condition evaluation methods were found useful and the methodologies used by the different approaches gave an indication of the possible effects of various factors on pavement condition. Maintenance effect measures found in the literature such as change in pavement conditions and other concepts were used in the development of the methodology in the present research. Some of the procedures and results found in the literature were used to confirm the analysis and to justify the output of the present research effort.

Most of the studies in the literature did not use pavement roughness as a direct measure of pavement condition. In addition, the effects of individual pavement routine maintenance activities on pavement condition were not considered. In the present research, the effect of

routine maintenance expenditure level on pavement condition was categorized by activity or group of activities. Pavement roughness was used as a direct aggregate quantitative measure of pavement condition, because network-wide roughness data are most commonly available.

CHAPTER 3

THE CONCEPTUAL BASIS FOR ASSESSING ROUTINE MAINTENANCE EFFECTS

3.1 Introduction

In this research, a concept is introduced to explain the effects of various levels of routine maintenance on pavement deterioration and pavement service life. Assuming maintenance policies and technology remain the same within a maintenance management unit of a highway agency, various levels of maintenance are represented in terms of expenditure. The need for this concept resulted from the fact that existing approaches cannot be directly used to evaluate either the costs or the impacts of alternative routine maintenance activities pavement performance over time. This approach is based on the concepts and results developed in various studies in the United States and the Highway Design and Maintenance Standards (HDM) Studies conducted by the World Bank.

3.2 Basis of the Approach

Pavement performance is a result of combined effects of traffic load, environment, age, initial design and construction, and past maintenance. The most widely used aggregate pavement performance model is the relationship between axle loading and pavement deterioration developed through the AASHO Road Test of the early 1960s. This relationship has been summarized in the AASHTO Interim Guide for Design of Pavement Structures [51]. The AASHO Road Test was conducted over a period of two years. This time period does not reflect the expected service period of 20 years or more for most pavements. In addition to that, during the Road Test a maintenance policy was implemented to permit only minor maintenance so as to keep test traffic operating as much as possible [52].

The aggregate pavement performance approach proposed by Fwa and Sinha [12] was based upon the serviceability performance concepts developed at the AASHO Road Test. The concept of zero-maintenance performance was introduced for the purpose of estimating the actual total pavement damage of a pavement. The pavement damage represented by this zero-maintenance curve was considered as the total damage caused by the combined action of all load and non-load factors (environmental factors). The aggregate performance approach evaluated the effects of maintenance by

associating pavement performance with a level of routine maintenance expenditure.

Several problems were faced by Fwa and Sinha in applying the aggregate approach. First, each performance analysis must be performed on a uniform highway route with homogeneous pavement characteristics. This led to the problem of having relatively few data points in applying the approach. Second, a proportionality assumption was used in calculating the pavement damage responsibilities of load-related and non-load-related effects. Third, the linearity assumption was used to relate level of pavement routine maintenance and pavement performance.

In the AASHTO performance equations [51] and aggregate pavement performance approach [12], the Present Serviceability Index (PSI) was used as a measure of pavement performance. The pavement damage was explained by Equivalent Single Axle Load (ESAL) involved in the analysis period. In reality, there is no comprehensive information on truck counts and, in many cases, no accurate procedures for computing ESAL. Furthermore, there are no absolute measures of load effects and pure environmental effects.

In the present study, in order to introduce the proposed approach, the following initial assumptions were made:

i. Pavement roughness can be used as a direct quantitative measure of pavement performance instead of PSI. This assumption is derived from results of several studies [53,54] which concluded that, in many instances, the use of roughness measurements alone is sufficient for predicting the serviceability index. In several studies, different models were developed to estimate serviceability as a function of roughness [55,56]. Roughness was used to predict pavement performance in Brazil and Kenya [37,38]. The International Roughness Index (IRI) was used as a roughness scale throughout the HDM studies [39,40,41,42] and it was employed to predict pavement deterioration and maintenance effects. The roughness data are readily available in most highway agencies and such items as user costs are more directly related to pavement surface roughness than PSI.

ii. Pavement age since the most recent reconstruction or resurfacing can be used to represent the combined effect of traffic, environmental, and their interaction for a small range of traffic volume as well as for a small variation in climatic conditions. Since pavement age alone can account for about 80% of the variations in damage responsibilities [12], this assumption is reasonably valid and pavement age can be

used as a measure of pavement service life.

iii. Pavement type and highway class represent initial design and construction.

3.3 Interface Between Routine Maintenance and Resurfacing

The line of separation between routine maintenance of pavements and major maintenance activities is flexible and the distinction between different maintenance policies is not always clear. The definition of routine and major maintenance is often mixed. This is because of different factors influencing maintenance operations such as maintenance organization, technology, unit costs, and methods of data collection and reporting. As defined by AASHTO [48], maintenance involves the provision of little or no new structural capacity. For example, patching, mudjacking, joint filling, surface treatment, and resurfacing or overlay of a thickness less than 3/4" and extending over less than 500 feet are classified as maintenance activities. As stated in AASHTO policy, the expenditure of these activities must be reflected in the maintenance budget supported by state and local taxes.

In the demand responsive approach [28], maintenance activities were divided based on their relative frequency into two categories: routine and periodic maintenance.

Routine maintenance consisted of activities performed on a regular or continual basis, while periodic maintenance included work undertaken at longer intervals of the pavement life. In the HDM studies [41,42], maintenance was specified as either scheduled at specific time intervals or condition responsive at specified threshold levels of pavement condition. Five categories of maintenance were considered, in order of descending priority: reconstruction, overlay, resealing, preventive treatments such as fog seal and slurry seal, and patching. Other activities such as crack sealing and joint filling were not included or even classified in the HDM studies.

As defined by Cation and Shahin [49], patching was considered a repair procedure while crack sealing, chip sealing, slurry sealing, and thin overlaying were considered preventive maintenance. Smith et al. [50] has separated maintenance from rehabilitation by using the Pavement Condition Index (PCI) definition. Based on that, all treatments which replace, rework or add a new surface to the existing pavement and consequently return PCI to 100 were considered rehabilitation activities. Reconstruction, all overlays, and surface recycling are examples of these activities. On the other hand, all treatments which do not completely cover the existing surface of the pavement and do not increase PCI to 100, such as seal coating, patching,

and crack sealing were considered routine maintenance activities.

To study the effectiveness of various routine maintenance activities on a long term basis, there is a need to differentiate between basic routine maintenance activities and improvement activities such as resurfacing. This need also requires the definition of other maintenance activities which can serve as an interface between routine maintenance and resurfacing activities. Byrd and Sinha [88] defined seal coating and thin overlay as the interface between basic routine maintenance and resurfacing.

Routine maintenance comprises those pavement activities undertaken on a regular basis to serve as preventive measures against deterioration of the pavement or as corrective measures to repair minor pavement damage. Activities such as crack sealing, shallow and deep patching, cutting relief joints, joint and bump burning, and joint filling form the basic level of routine maintenance. On the other hand, activities such as seal coating (sand sealing and chip sealing) and premix leveling are higher level maintenance activities with a greater degree of impact on pavement service life. Therefore, these activities can be defined as the interface between basic routine maintenance and resurfacing.

Resurfacing is defined in this study as the placement of additional surface material over an existing pavement to improve serviceability or to provide additional strength. Resurfacing is considered a first level of improvement which significantly affects serviceability as opposed to higher levels of improvement such as restoration or rehabilitation (requiring improvement of structural support) and reconstruction (where an old pavement structure is removed and replaced). Figure 3.1 shows the hierarchy of pavement maintenance and improvement activities [88].

3.4 Relationship Between Pavement Age and Routine Maintenance

To study the impact of routine maintenance on pavement condition or performance, two criteria are presented. First, there is a direct relationship between pavement age and pavement performance for highway sections with similar ranges of traffic volume. In such a case, pavement age can be used to represent pavement condition over time. Second, the effect of routine maintenance on pavement condition can be related only if maintenance has been performed to respond to definite maintenance needs.

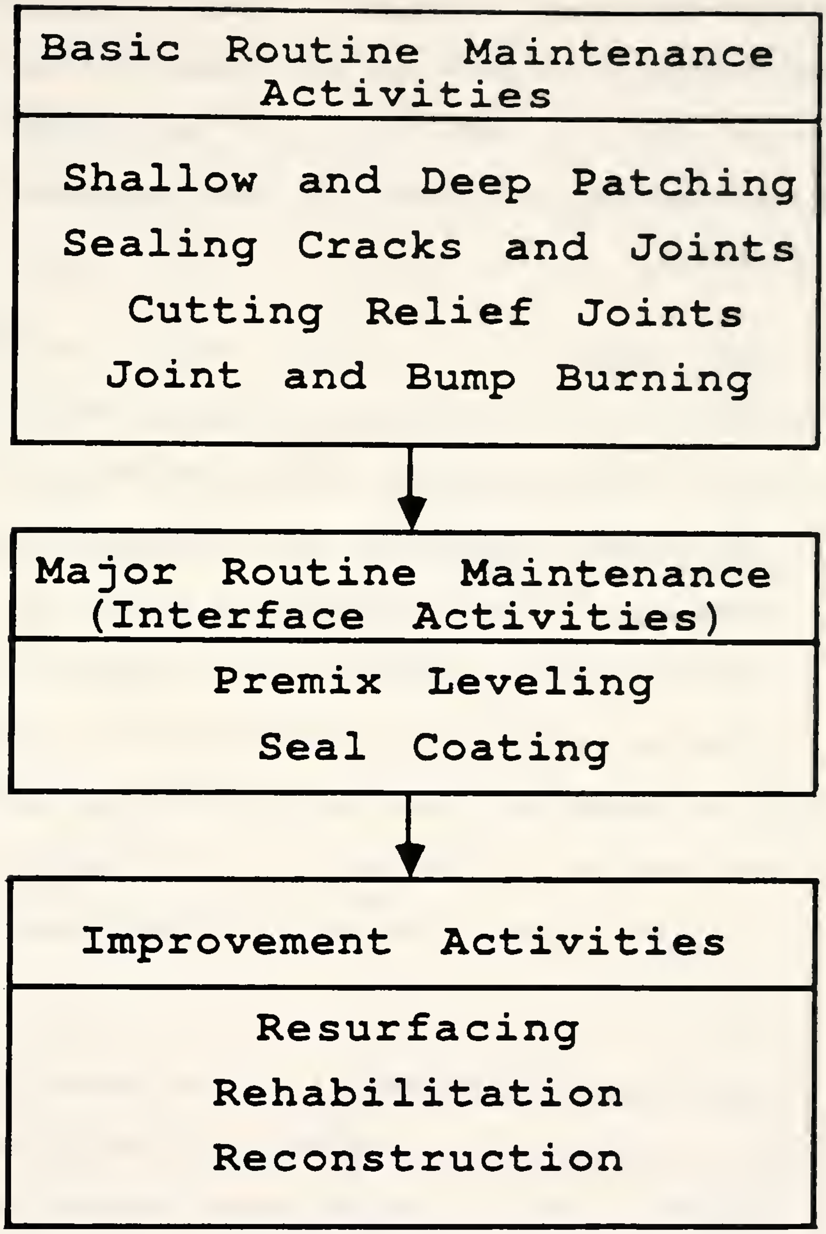


Figure 3.1 Hierarchy of Pavement Maintenance and Improvement Activities. [88]

Based on these two criteria, a relationship between pavement age and routine maintenance can be introduced. Pavement age is divided in this approach into three groups: Age I, Age II, Age III. The effectiveness of routine maintenance can be expected to vary depending on age group as follows:

i. Age Group I - In this group, pavements are in excellent or very good condition. The period may range up to about five years after reconstruction or major improvement depending on several factors including highway class, pavement type and thickness, construction standard and traffic. The need for routine maintenance in this group is usually low, and accordingly the effectiveness of routine maintenance is small. Furthermore, if routine maintenance provided exceeds the need, pavement roughness may even increase.

ii. Age Group II - Pavements in this group are in fair to good condition. Pavement ages may be in the range of about 5 to 15 years after major improvement or reconstruction. Pavements in this group may receive increasingly more routine maintenance with time and exhibit greater changes in surface roughness. The effectiveness of routine maintenance can be expected to be the highest for pavements in this group.

iii. <u>Age Group III</u> - Pavements in this group are in poor condition. The pavement age may range from 10 years to more than 15 years. The need for major improvement or resurfacing in this group is more than the need for routine maintenance. So, the effectiveness of routine maintenance would be little for this age group as for Group 1.

Figure 3.2 presents graphically the above hypotheses. Initially, the maintenance effectiveness is expected to increase to a maximum point which falls within the range of Age Group II. After that, the effectiveness would start to decline to a point when resurfacing would be needed. In this figure, it is assumed that this is the point of zero effectiveness, although it may not necessarily exist in practice. The curve used is considered merely demonstrative and not necessarily the expected shape.

Considering the above, at stage n, the pavement needs to be resurfaced if no maintenance during its life is applied. Stages n_1 and n_2 represent points when the pavement needs to be resurfaced with applied routine maintenance expenditure levels of L_1 and L_2, respectively. Pavements have been found to require rehabilitation at periods between 5 and 15 years [58]. It can be assumed that Age Group II covers this period. Considering the pavement service life is about 20 years, the period of Age

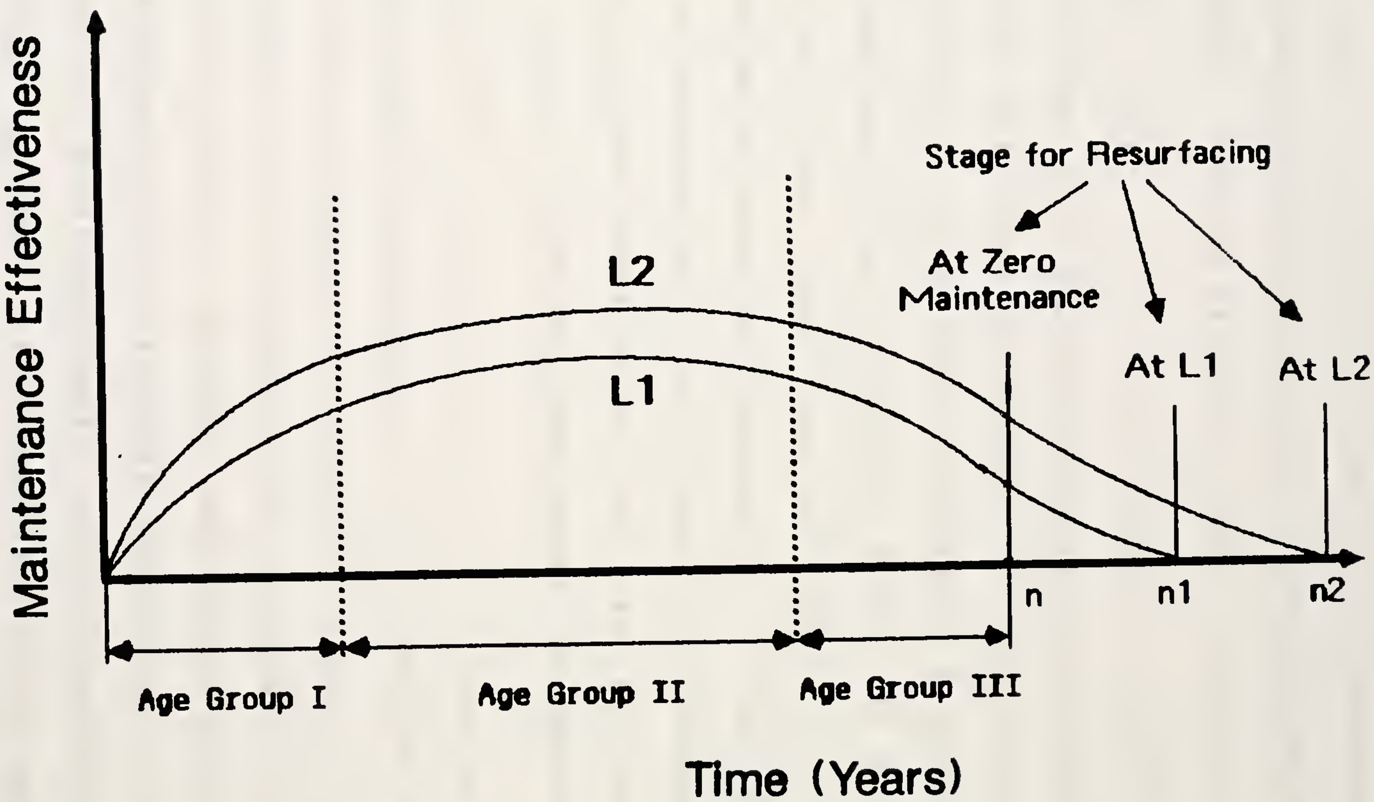


Figure 3.2 Schematic Diagram of Routine Maintenance Effectiveness for Different Age Groups.

Group II can be expected to be larger than Age Groups I and III. However, it should be noted that the ranges of these groups may be different for different pavement types.

3.5 Concept of Deterioration in Pavement Surface Condition

Pavement deterioration has been defined using different concepts in previous studies. In the 1972 AASHTO Interim Guide [51], pavement deterioration was represented by a term known as serviceability loss, or PSI loss. The PSI loss at time t, as shown in Figure 3.3, is equal to the difference between the initial PSI and the PSI at time t, that is,

$$\text{PSI loss at time } t = (\text{PSI})_0 - (\text{PSI})_t$$

Another measure of pavement deterioration was introduced by Fwa and Sinha [12] for use in pavement performance analysis. It is known as the PSI-ESAL loss of the pavement at the time of analysis, designated as stage n in Figure 3.4. This quantitative measure of pavement deterioration provided an additional dimension to the traditional measure, PSI loss. While PSI loss is an assessment of pavement condition at a point of time in pavement life, PSI-ESAL loss provides a measure of pavement deterioration covering the entire analysis period. In addition, the use of PSI-ESAL loss facilitates the

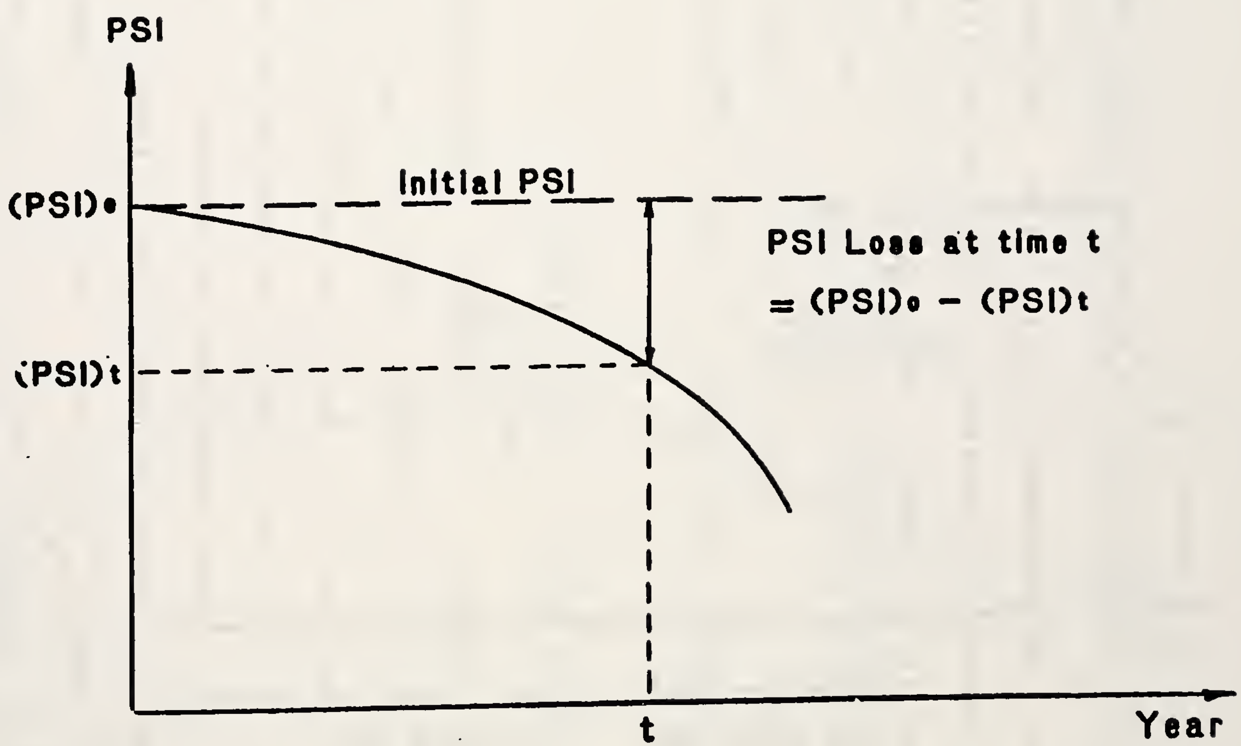


Figure 3.3 Pavement Serviceability Time History Plot. [12]

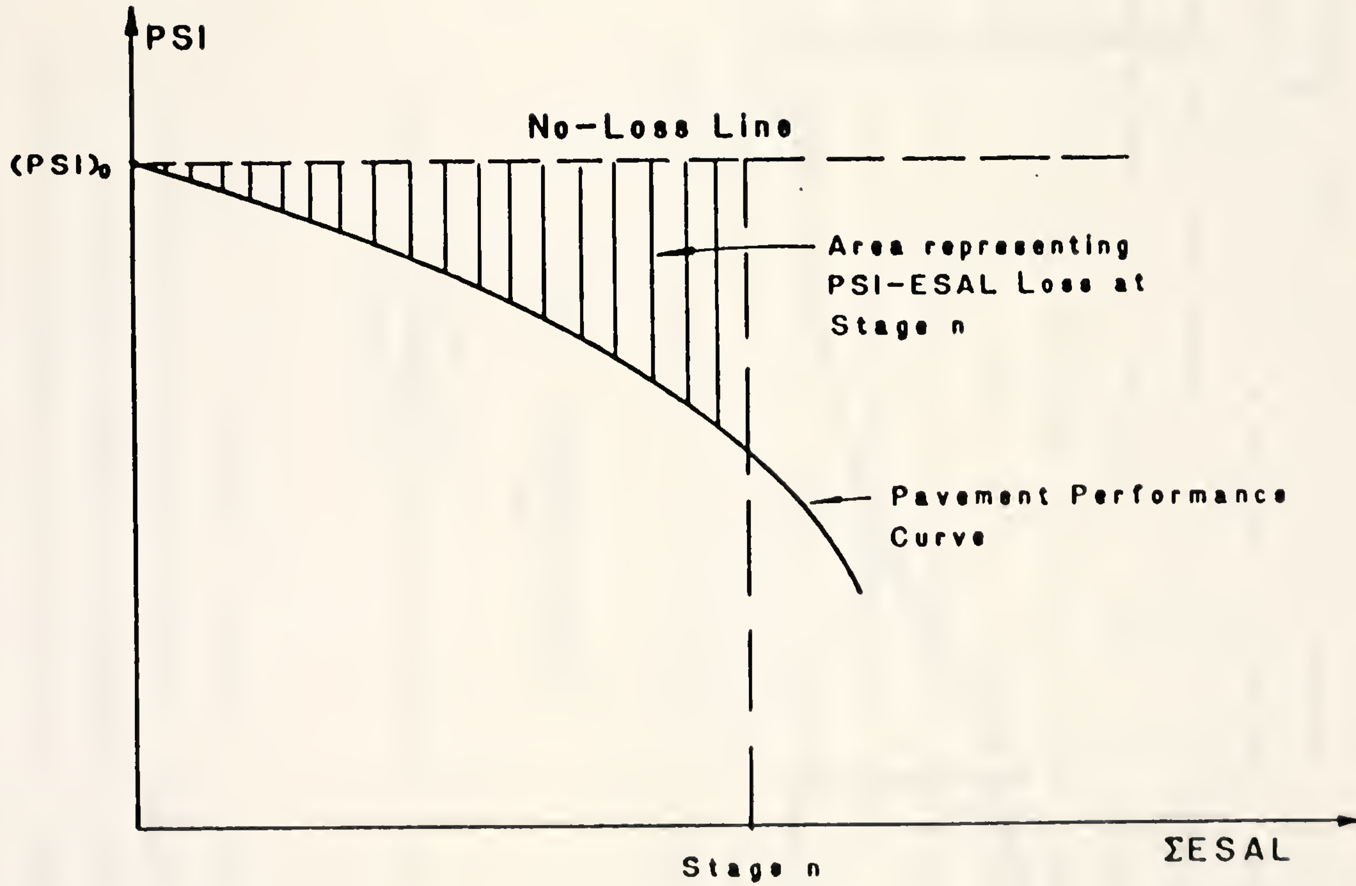


Figure 3.4 PSI-ESAL Loss as a Measure of Pavement Deterioration. [12]

incorporation of traffic loading and environmental effects into pavement performance.

In the present study, as stated under Section 3.2, pavement roughness was used as a direct measure of PSI. The progression of pavement roughness over time can be considered as shown in Figure 3.5. Knowing pavement roughness before and after applying different levels of routine maintenance on a given section of a highway, deterioration in pavement surface condition can be measured as a change in pavement roughness or a rate of change in pavement roughness. Figure 3.6 shows deterioration in pavement surface condition during a given period of time. The associated measures are calculated as follows:

$$\Delta RN = RN_{t+1} - RN_t \tag{3.1}$$

$$RRN = \frac{RN_{t+1} - RN_t}{RN_t} \tag{3.2}$$

where,

RN_t = pavement roughness in year t (t=1,...,n)

RN_{t+1} = pavement roughness in the next year

ΔRN = change in pavement roughness

RRN = rate of change in pavement roughness

This concept will be used to reflect the effectiveness of routine maintenance in reducing deterioration in

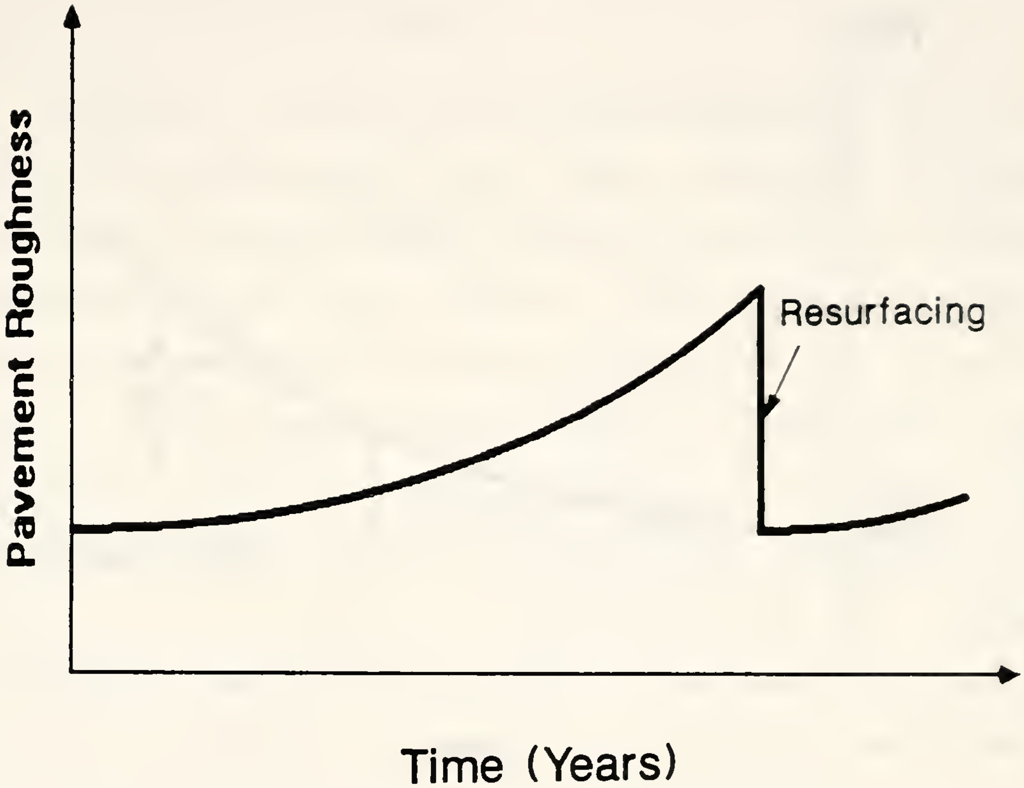


Figure 3.5 Progression of Pavement Roughness Over Time. [41,42]

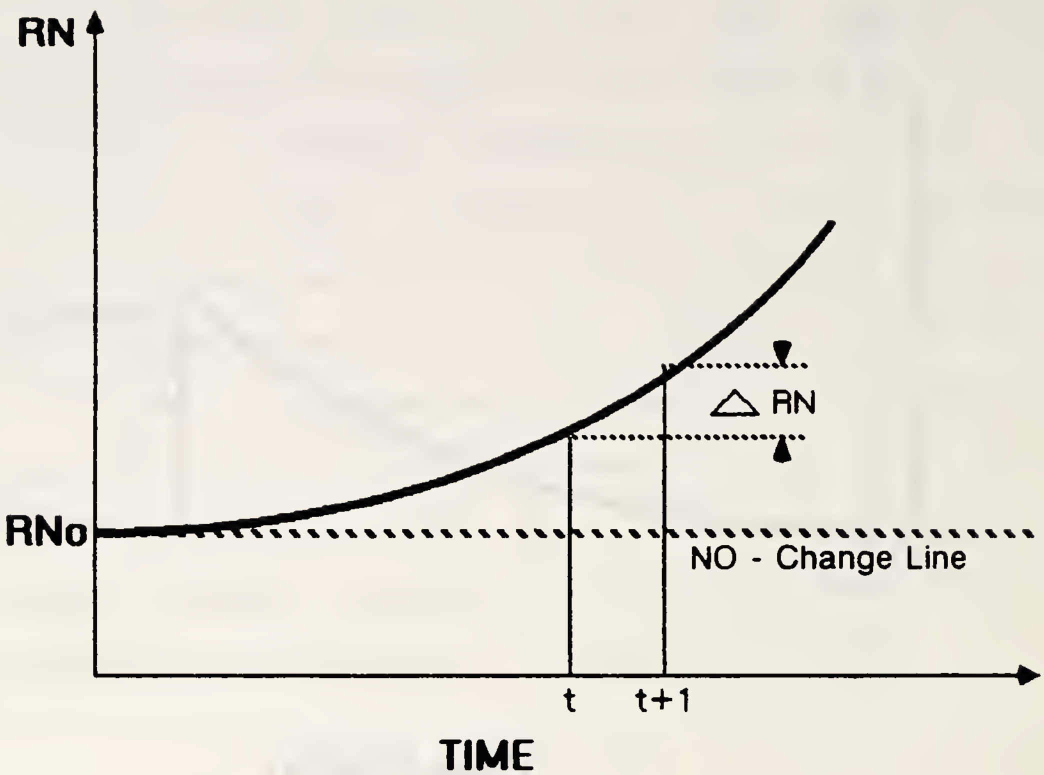


Figure 3.6 Schematic Diagram Showing Pavement Surface Deterioration During a Period of Time.

pavement surface condition. As explained in Figure 3.6 and expressed in Equations 3.1 and 3.2, the change in surface condition will initially be assessed as defined by using data over a one-year period.

To predict the effect of routine maintenance level on pavement deterioration, one should introduce pavement performance over time under different levels of routine maintenance. Fwa and Sinha [12] related pavement performance to levels of routine maintenance as shown in Figure 3.7. This figure shows schematically the performance curves for three sections of pavement with uniform pavement characteristics and traffic loading history, but each with a different level of routine maintenance. Each of the three performance curves is labeled with a value, Si, which is the routine maintenance expenditure associated with maintenance level, Li.

Since routine maintenance expenditure level can be expected to represent both the quality and quantity of maintenance work, it can be used as a measure of the level of routine maintenance performed on a given pavement. Accepting this fact and considering Fwa and Sinha [12] performance curves, pavement roughness can be related to different expenditure levels of routine maintenance (Li) as shown in Figure 3.8.

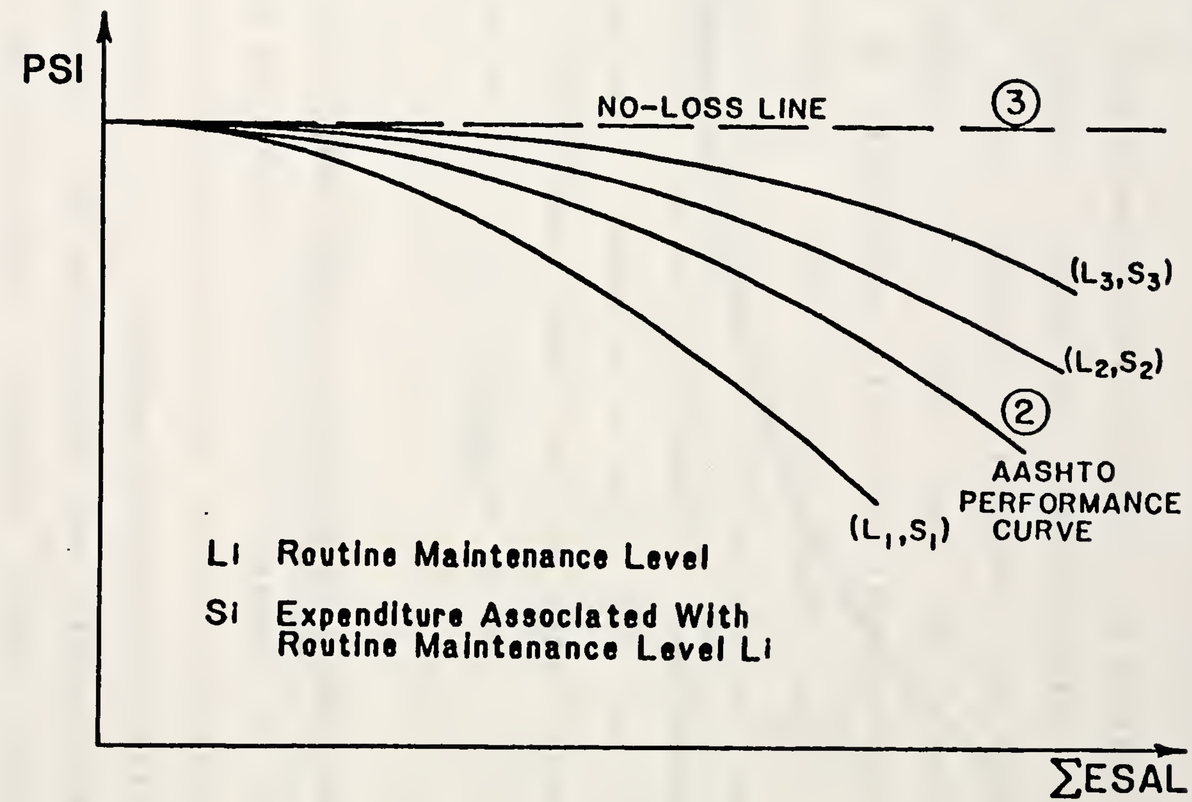


Figure 3.7 Schematic Diagram Showing Pavement Performance Curves with Different Levels of Routine Maintenance. [12]

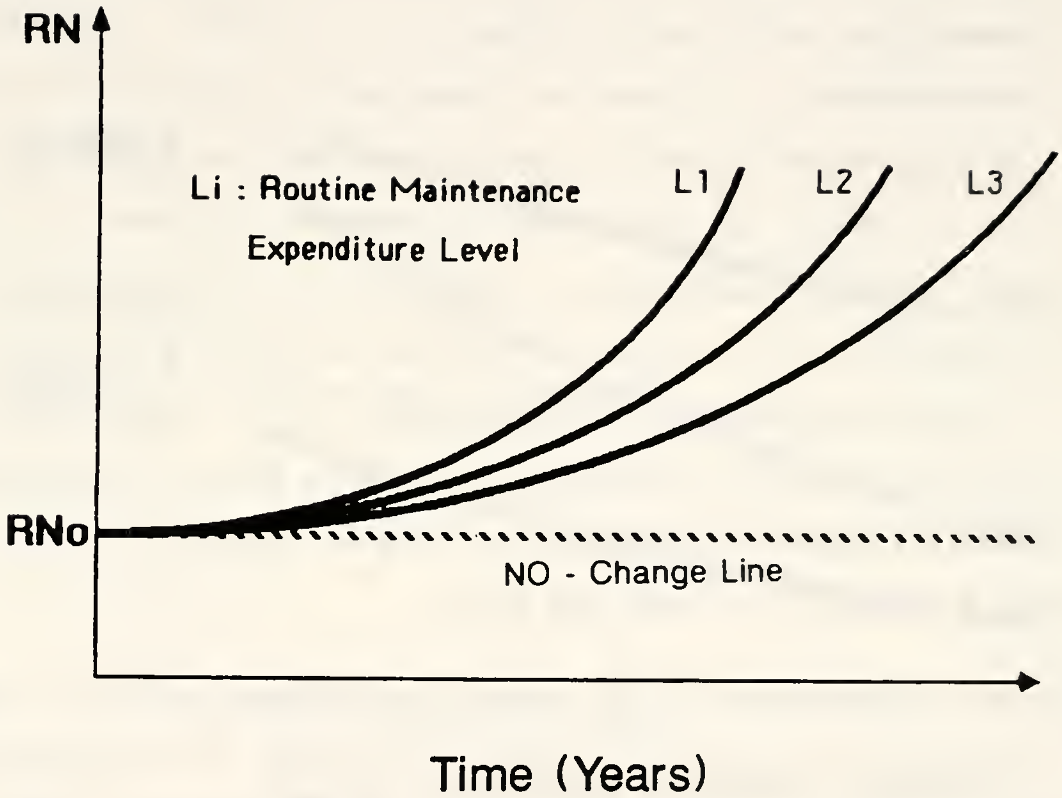


Figure 3.8 Schematic Diagram Showing Pavement Roughness Curves with Different Expenditure Levels of Routine Maintenance

3.6 Effectiveness of Routine Maintenance Expenditure

Routine maintenance effectiveness is represented by the reduction in the deterioration in pavement surface condition per unit change in routine maintenance expenditure. It can be measured in two different ways. First, the deterioration in pavement surface condition can be expressed as the change in pavement roughness. This is an absolute measure of change in pavement surface condition; so there is a need to tie this measure with another dimension to be meaningful. Since the change in roughness varies from one age group to another, maintenance effectiveness for a given increase in expenditure level is not the same for each age group.

Figure 3.9 shows the relationship between routine maintenance expenditure level and change in roughness (ΔRN) for different age groups, on the assumption that the maintenance policy remains the same. Maintenance policy (P_j) represents one routine maintenance activity or group of activities. Also, maintenance policy can represent the administrative system of management unit which performs the maintenance work. Maintenance effectiveness for Age Group I is calculated as follows:

$$M(1,2)I=\frac{\Delta RN_{1,I}-\Delta RN_{2,I}}{L_2-L_1} \qquad (3.3)$$

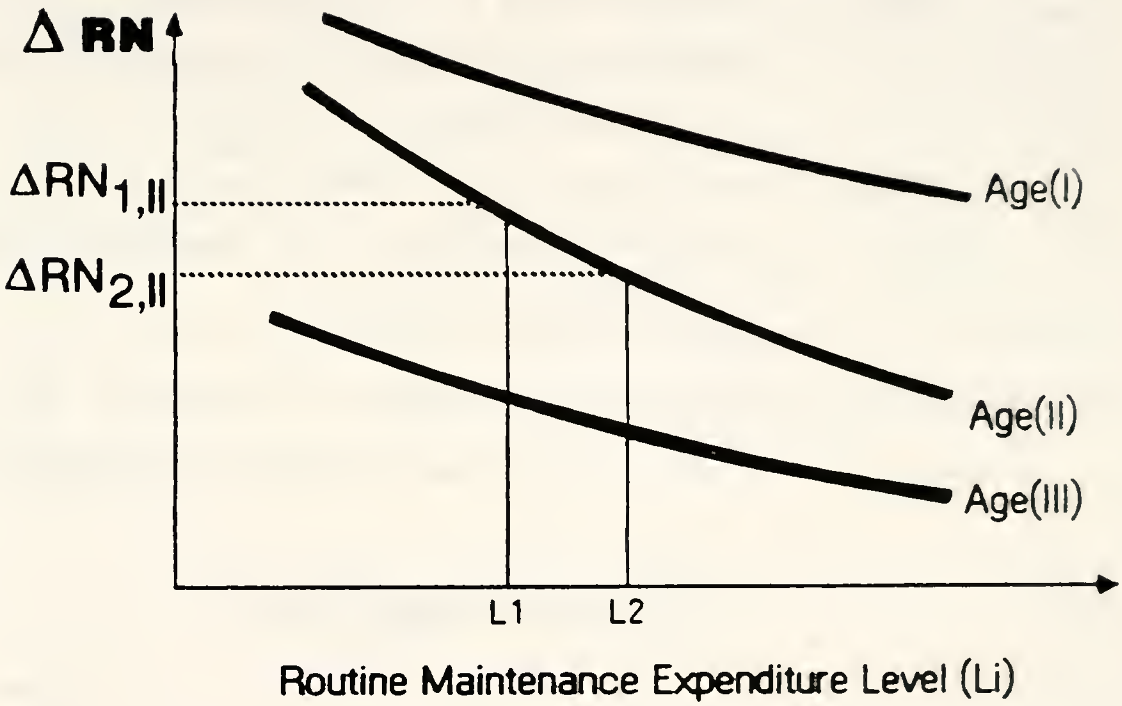


Figure 3.9 Schematic Diagram Showing Maintenance Effectiveness for Different Age Groups Under the Same Maintenance Policy.

where,

$M(1,2)I$ = maintenance effectiveness associated with an increase in expenditure level from L_1 to L_2 for Age Group I.

$\Delta RN_{1,I}$ = deterioration in pavement surface condition associated with expenditure level L_1 for Age Group I.

$\Delta RN_{2,I}$ = deterioration in pavement surface condition associated with expenditure level L_2 for Age Group I.

Maintenance effectiveness for Age Groups II and III are calculated as shown in Equations 3.4 and 3.5, respectively:

$$M(1,2)II=\frac{\Delta RN_{1,II}-\Delta RN_{2,II}}{L_2-L_1} \tag{3.4}$$

$$M(1,2)III=\frac{\Delta RN_{1,III}-\Delta RN_{2,III}}{L_2-L_1} \tag{3.5}$$

The impact of routine maintenance expenditure level would be different for pavements in different age groups. However, in Figure 3.9, the relative slope of each age group curve is considered important not the location of each curve.

The second measure of maintenance effectiveness can be introduced when the deterioration in pavement surface condition is expressed as the rate of change in pavement roughness. In this case, pavement age and traffic effects are implicitly included in representing pavement surface condition. Figure 3.10 shows the relationship between routine maintenance expenditure level and rate of change in pavement roughness (RRN) for two policies of routine maintenance. In this figure, policy P_2 is better than policy P_1 or expected to achieve more reduction in deterioration in pavement surface condition. For example, the maintenance effectiveness applying policy P_1 is calculated as follows:

$$M(1,2)1=\frac{RRN_{11}-RRN_{21}}{L_2-L_1} \tag{3.6}$$

where,

$M(1,2)1$ = maintenance effectiveness associated with an increase in expenditure level from L_1 to L_2 applying policy P_1.

RRN_{11} = deterioration in pavement surface condition associated with expenditure level L_1 of policy P_1.

RRN_{21} = deterioration in pavement surface condition associated with expenditure level L_2 of policy P_1.

Maintenance effectiveness applying policy P_2 is calculated as shown in Equation 3.7:

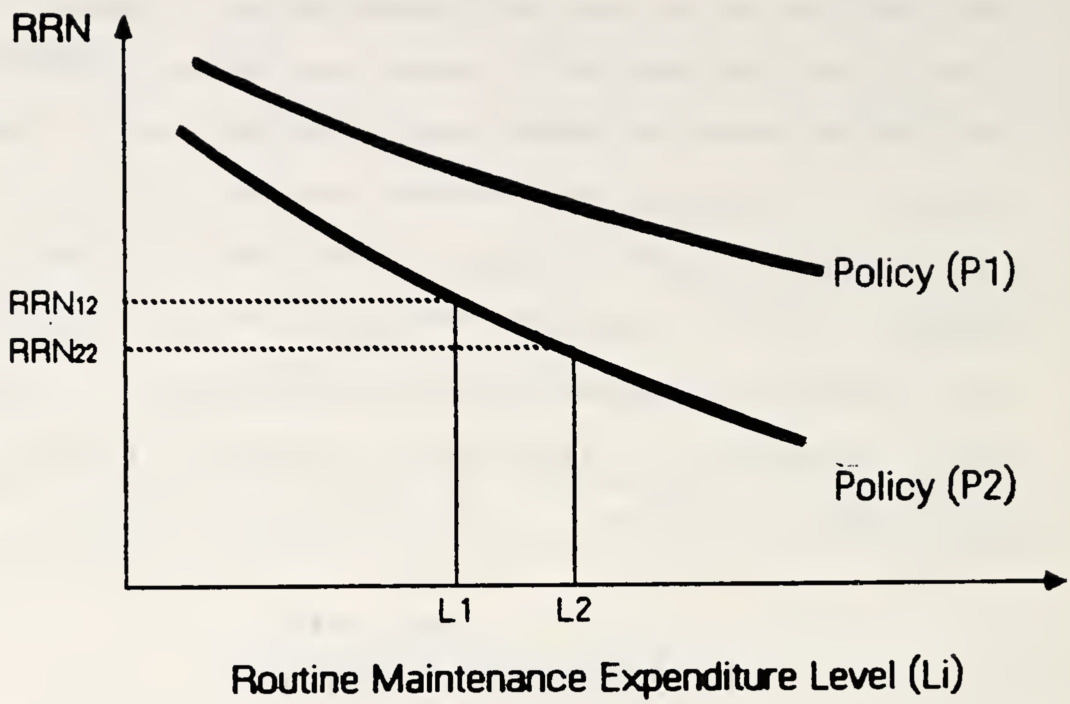
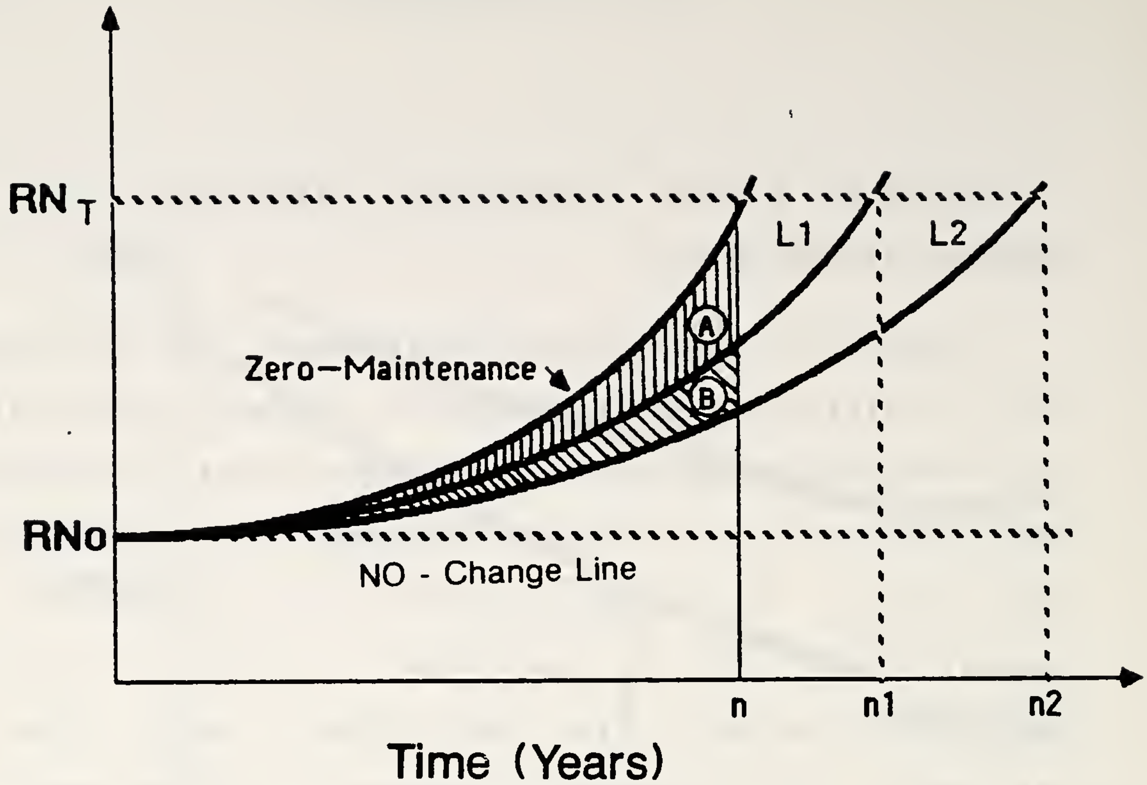


Figure 3.10 Schematic Diagram Showing Maintenance Effectiveness Applying Different Maintenance Policies.

$$M(1,2)2=\frac{RRN_{12}-RRN_{22}}{L_2-L_1} \qquad (3.7)$$

3.7 Effect of Routine Maintenance Expenditure Level on Pavement Service Life

Figure 3.11 shows pavement performance over time under three different maintenance levels. Pavement service life (n) under zero-maintenance can be determined considering the fact that when pavement roughness reaches a terminal value (RN_T), the pavement needs to be resurfaced or reconstructed. RN_T is equivalent to 2.0 or 2.5 PSI depending on pavement type and highway class. Area A represents the improvement in pavement condition over time (n), if expenditure level L_1 is applied instead of zero-maintenance. Area A is also equivalent to the reduction in deterioration of pavement condition if L_1 is applied. Area B represents the improvement in pavement condition over time (n) if expenditure level is increased from L_1 to L_2. n_1 and n_2 represent pavement age at terminal pavement roughness (RN_T) for expenditure levels L_1 and L_2, respectively. $(n_1 - n)$ is the increment in pavement service life due to the routine maintenance expenditure at level L_1. Also, for expenditure level L_2, pavement service life increases by $(n_2 - n)$.



LEGEND

L i Routine Maintenance Expenditure Level

Area 'A' represents the Improvement in Pavement Condition if Maintenance Expenditure Level, L1 is applied.

Area 'B' represents the Improvement in Pavement Condition if Maintenance Expenditure Level increases from L1 to L2

RN_T Terminal Roughness Value at which resurfacing is Required.

Figure 3.11 Schematic Diagram Showing Effect of Routine Maintenance Expenditure Levels on Pavement Service Life.

3.8 Effect of Routine Maintenance on User Costs

Improved pavement conditions mean savings in user costs. Good quality and proper scheduling of maintenance would provide improvement in pavement condition. Roughness is a physical measure of irregularity of pavement surface and it has a direct effect on ride quality. Hence, it affects various components of user costs. User costs consist mainly of vehicle operating costs, travel time costs and accident costs. For planning, programming, and pavement management purposes, the concept of routine maintenance effectiveness and pavement performance can be extended to include also the effect of routine maintenance expenditure level on user costs.

The major cost studies conducted in Kenya, Brazil, the Caribbean, and India in the 1970's [59] have all demonstrated a strong relationship between user costs and pavement roughness. Figure 3.12 shows the general relationship between user costs and pavement roughness over time as observed in these studies. The effect of routine maintenance, however, was not fully considered in the HDM studies [41,42]; it was concluded that the effect of routine maintenance on user costs was very slight under the given maintenance scenarios. Zaniewski [60] also found that fuel consumption as a major component of vehicle operating costs was not affected by pavement condition in the United

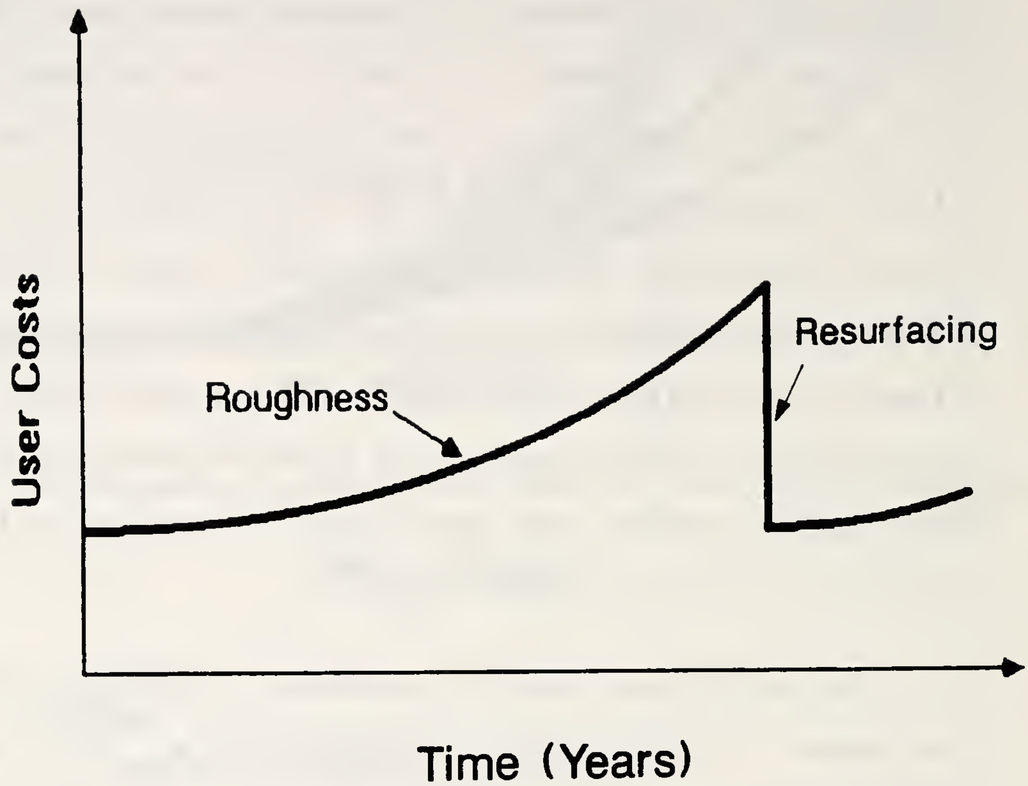
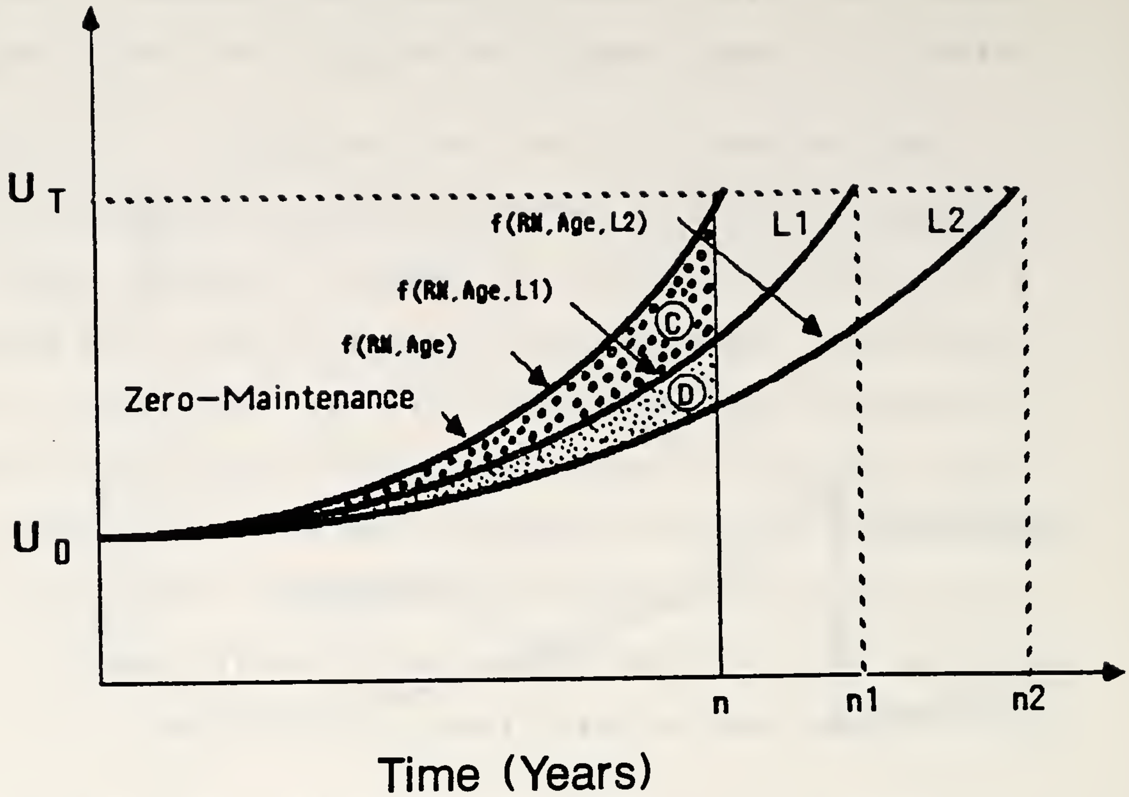


Figure 3.12 Effect of Pavement Roughness on User Costs Over Time. [59]

States. He did however find that pavement condition affected oil usage, vehicle maintenance and repair costs.

The determination of the influence of pavement condition on vehicle operating costs and accident rates is a very difficult task. It requires careful controlled experiments conducted over a period of time. The scope of the present research did not allow the assessment of the direct effect of routine maintenance expenditure level on user costs. It can be expected, however, that a change in pavement surface condition does directly affect user costs and the total of these costs over the entire service life of a pavement may be significant.

Figure 3.13 shows schematically the relationship between pavement roughness and user costs for two routine maintenance expenditure levels, L_1 and L_2, over time. Area C is the saving in user costs resulting from improvement in pavement condition after applying routine maintenance expenditure level L_1 instead of zero-maintenance. Area D is the saving in user costs over time if routine maintenance expenditure level increased from L_1 to L_2. This area corresponds to the effectiveness of maintenance or the extra improvement in pavement performance if expenditure level is increased to L_2.



LEGEND

L i Routine Maintenance Expenditure Level

Area 'C' represents the Saving in User Costs if Maintenance Expenditure Level, L1 is applied.

Area 'D' represents the Saving in User Costs if Maintenance Expenditure Level increases from L1 to L2

U_T User Cost corresponding to Terminal Roughness.

Figure 3.13 Schematic Diagram Showing Effect of Routine Maintenance Expenditure Level on User Costs.

In cases where user cost data are available, the effect of routine maintenance on pavement condition and consequently on user cost can be used in pavement life-cycle costing analysis. Applying principles of engineering economic analysis, different alternatives of maintenance expenditure level can be compared. A comparison can be made between the present value of different maintenance policies or expenditure levels and the present value of user costs associated with each policy.

3.9 Summary of the Proposed Methodology

This section provides a summary of the main features of the present study. The methodology is based on the aggregate performance approach developed earlier by Fwa and Sinha [12]. For assessing routine maintenance effects, three assumptions were made. First, pavement roughness was proposed to be used as a direct measure of pavement performance instead of PSI. Second, pavement age was used as a measure of pavement service life. Third, pavement type and highway class was assumed to represent initial design and construction.

Since the meaning of maintenance and rehabilitation operations in different studies are mixed, a differentiation between routine maintenance and other

improvement activities such as resurfacing was provided in this approach. Following that, a conceptual relationship between pavement age and routine maintenance was developed. In this relationship, pavement age was divided into three groups and the response of pavement condition to routine maintenance level within each group was illustrated. Routine maintenance level was quantified by maintenance expenditure.

Two measures of deterioration in pavement surface condition were introduced for the purpose of estimating the routine maintenance effectiveness. The first measure, change in pavement roughness, was considered an absolute measure of surface condition deterioration. Therefore, this measure was tied with pavement age in order to compute maintenance effectiveness for different age groups under a given maintenance policy. In the second measure, rate of change in pavement roughness, the effects of pavement age and traffic were implicitly included, and maintenance effectiveness was computed for different maintenance policies.

To study the effect of routine maintenance on timing of pavement resurfacing, a relationship between different levels of routine maintenance expenditure and pavement service life was schematically introduced.

CHAPTER 4

DEVELOPMENT OF THE DATA BASE

4.1 Introduction

The overall effectiveness of any Pavement Maintenance Management System (PMMS) is dependent on the accuracy and reliability of the data base. A major concern in this research was to develop a consistent data base for pavement routine maintenance, pavement condition, and pavement characteristics of the sections included in the study. The appropriate data were collected based on contract sections instead of highway sections. A contract section is that portion of a highway pavement that is contracted out to one contractor for a specific activity such as resurfacing. The pavement characteristics within a contract section are generally uniform. In contrast, a highway section, generally used to record maintenance information, may include a series of different contract sections with different pavement characteristics.

4.2 Data Sources

The data base was developed from three sources of information: routine maintenance records, roughness measurement records, and road life records. The data were obtained from various divisions of Indiana Department of Highways (IDOH) as described in the following sections.

4.2.1 Routine Maintenance Records

The overall maintenance of the highway network in Indiana is programmed and executed by the Division of Maintenance of the IDOH. The current data recording system in the IDOH Division of Maintenance includes filing daily work records on specified Crew Day Cards. The Crew Day Cards provide a means for authorizing work to be done and a record of work completed [61]. Each Crew Day Card represents one 8-hour day of any maintenance activity. Such cards include the following information:

1. Routine maintenance activity type.

2. Location where the activity was performed.

3. Number of crew members and corresponding man-hours.

4. Equipment used and corresponding units of miles or hours.

5. Work date.

6. Materials used and corresponding quantities.

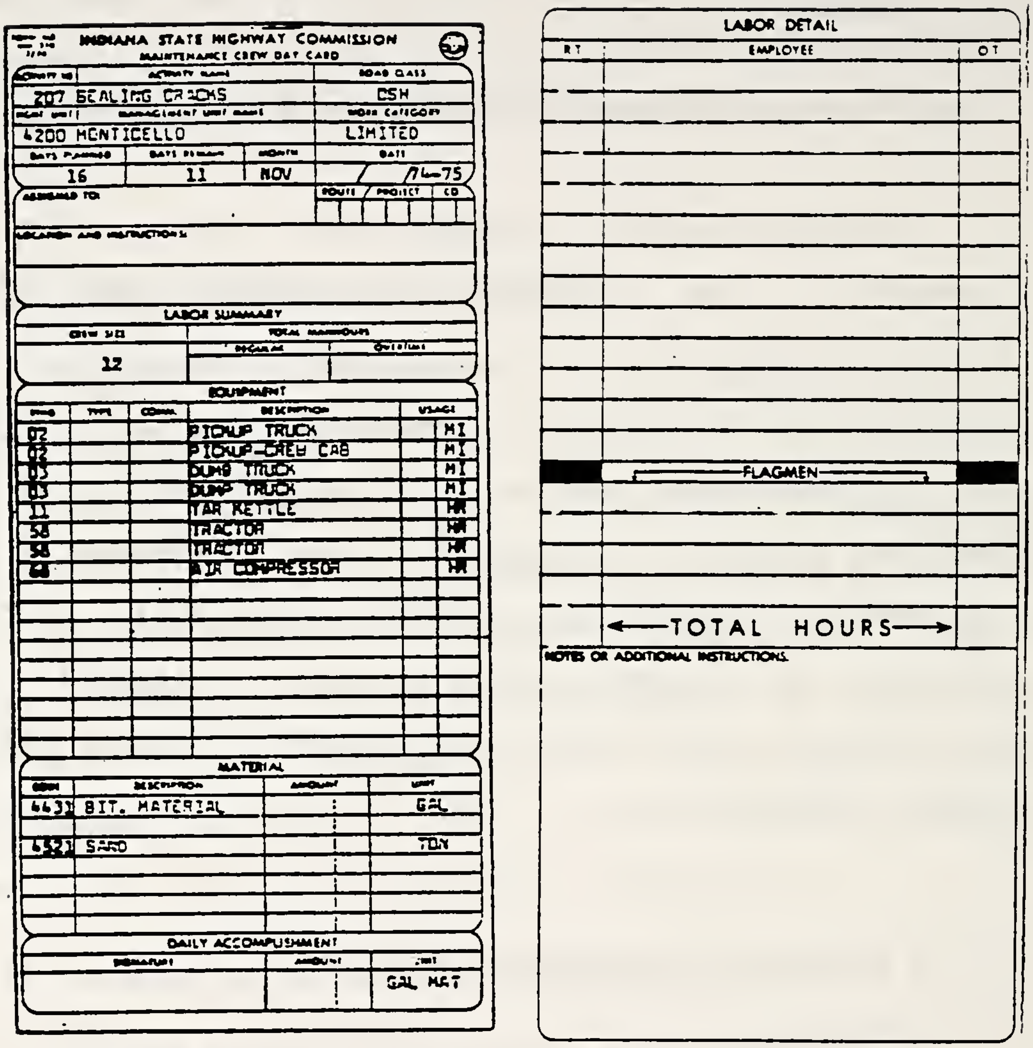
7. Total daily accomplishment in terms of production units.

8. Other information (remarks and other notes).

The Crew Day Card information is computer coded and recorded by the Division of Maintenance. The available data are presented by highway section. Consequently, the original Crew Day Cards were considered the basic source of routine maintenance records in the development of the data base for this study. Figure 4.1 shows an example of a Crew Day Card. In addition, only routine maintenance activities related to highway pavement were considered. These activities along with code numbers and production units are listed in Table 4.1.

4.2.2 Roughness Measurements Records

As a result of a cooperative research program between IDOH Division of Research and Training (DRT) and Purdue University in 1976 to develop a system for the evaluation of pavement condition in Indiana, IDOH began a systematic recording of pavement roughness for all state highways in


INDIANA STATE HIGHWAY COMMISSION
MAINTENANCE CREW DAY CARD

ACTIVITY NO	ACTIVITY NAME	ROAD CLASS
207	SEALING CRACKS	CSH
MGMT UNIT	MANAGEMENT UNIT NAME	WORK CATEGORY
4200	MONTICELLO	LIMITED

DAYS PLANNED	DAYS REMAIN	MONTH	DATE
16	11	NOV	/ /74-75

ASSIGNED TO: | ROUTE / PROJECT | CO

LOCATION AND INSTRUCTIONS:

LABOR SUMMARY

CREW SIZE	TOTAL MANHOURS REGULAR	OVERTIME
12		

EQUIPMENT

EQUIP	TYPE	COMM.	DESCRIPTION	USAGE
02			PICKUP TRUCK	MI
02			PICKUP-CREW CAB	MI
03			DUMP TRUCK	MI
03			DUMP TRUCK	MI
11			TAR KETTLE	HR
58			TRACTOR	HR
58			TRACTOR	HR
68			AIR COMPRESSOR	HR

MATERIAL

ITEM	DESCRIPTION	AMOUNT	UNIT
4431	BIT. MATERIAL		GAL
4521	SAND		TON

DAILY ACCOMPLISHMENT

SIGNATURE	AMOUNT	UNIT
		GAL MAT

LABOR DETAIL

RT	EMPLOYEE	OT
	FLAGMEN	
	←TOTAL HOURS→	

NOTES OR ADDITIONAL INSTRUCTIONS.

Figure 4.1 Example of a Crew Day Card.

Table 4.1 Pavement Routine Maintenance Activities.

Activity Name	Code Number	Production Units
Shallow Patching	201	Tons of Mix
Deep Patching	202	Tons of Mix
Premix Leveling	203	Tons of Premix
Seal Coating	205	Lane-Miles
Sealing Longitudinal Cracks and Joints	206	Linear Miles
Sealing Cracks	207	Lane-Miles
Cutting Relief Joints	209	Linear Feet
Joint and Bump Burning	214	Bumps Removed
Others	219	Man-Hours

1979. At the beginning of this study, seven years (1979 to 1985) of complete roughness records were available from computer files at the DRT. These computer files include the following information:

1. Contract number
2. Contract length
3. Surface type and texture
4. Roughness measurements recorded usually every mile and averaged over a contract section
5. Landmarks
6. Date of roughness measurements
7. Date of construction or last major maintenance (Year opened to traffic)
8. 1978 average daily traffic (ADT) in one direction
9. Number of lanes in each direction
10. Other information

4.2.3 Road Life Records

The Road Life Records are available in the IDOH Division of Planning. These records are based on actual

contract documents and include information about all highways. This information includes the following:

1. Activity Type (new construction, reconstruction, or resurfacing)

2. Year of last activity application

3. Year of last activity completion

4. Surface type and thickness

5. Base type and thickness

6. Pavement width

7. Contract length

The basic source for ADT and percentage of trucks information used to develop the data base is the traffic counts and studies performed by the Division of Planning. All 92 counties in Indiana were found to have complete traffic maps for 1981-1985.

4.3 Design of Experiment

The IDOH has six districts. Five districts have six subdistricts, and one district has seven subdistricts, with a total of thirty-seven subdistricts. In each subdistrict, there are three to four units which actually perform the

field work. Sharaf and Sinha [9] found the subdistrict to be the suitable management unit in the development of pavement maintenance data base. They developed a comprehensive data base for the entire highway system in Indiana and all subdistricts were included. The highway section was considered as a basic unit in their study.

In the present study also the subdistrict was considered the suitable management unit. However, a comprehensive data base could not be developed for all subdistricts because of the difficulty of manually processing several thousands of Crew Day Cards to extract routine maintenance activity information and to match the data with appropriate contract sections. Hence, ten subdistricts were selected for the analysis.

To represent routine maintenance for the entire highway system, the desirable approach would have been to use a random sampling technique. However, in this study this technique was not considered effective and the subdistricts were instead selected based on the following considerations:

1. To include sections from Interstate highways.

2. To represent the administrative system so that at least one subdistrict was selected from each district.

3. To represent the entire state geographically.

4. To cover both regions in the State (North and South)

Finally, six subdistricts were selected from the South region and four subdistricts from the North region. Figure 4.2 shows the locations of the selected subdistricts. These subdistricts along with corresponding districts and code numbers are listed in Table 4.2.

4.4 Selection of Contract Sections

Having selected the subdistricts, the DRT computer files were used to select the contract sections in each subdistrict. Since one of the objectives in this research was to study the effect of routine maintenance activity expenditure levels on the rate of change in surface roughness or change in surface roughness as a measure of deterioration in pavement surface condition, the two most recent roughness measurements (1984, 1985) were used. Only those sections that did not receive any major maintenance or resurfacing between two roughness measurements were selected.

The data on roughness measurement on each contract section for 1984 and 1985 along with other information stated in Section 4.2.2 were recorded in newly created

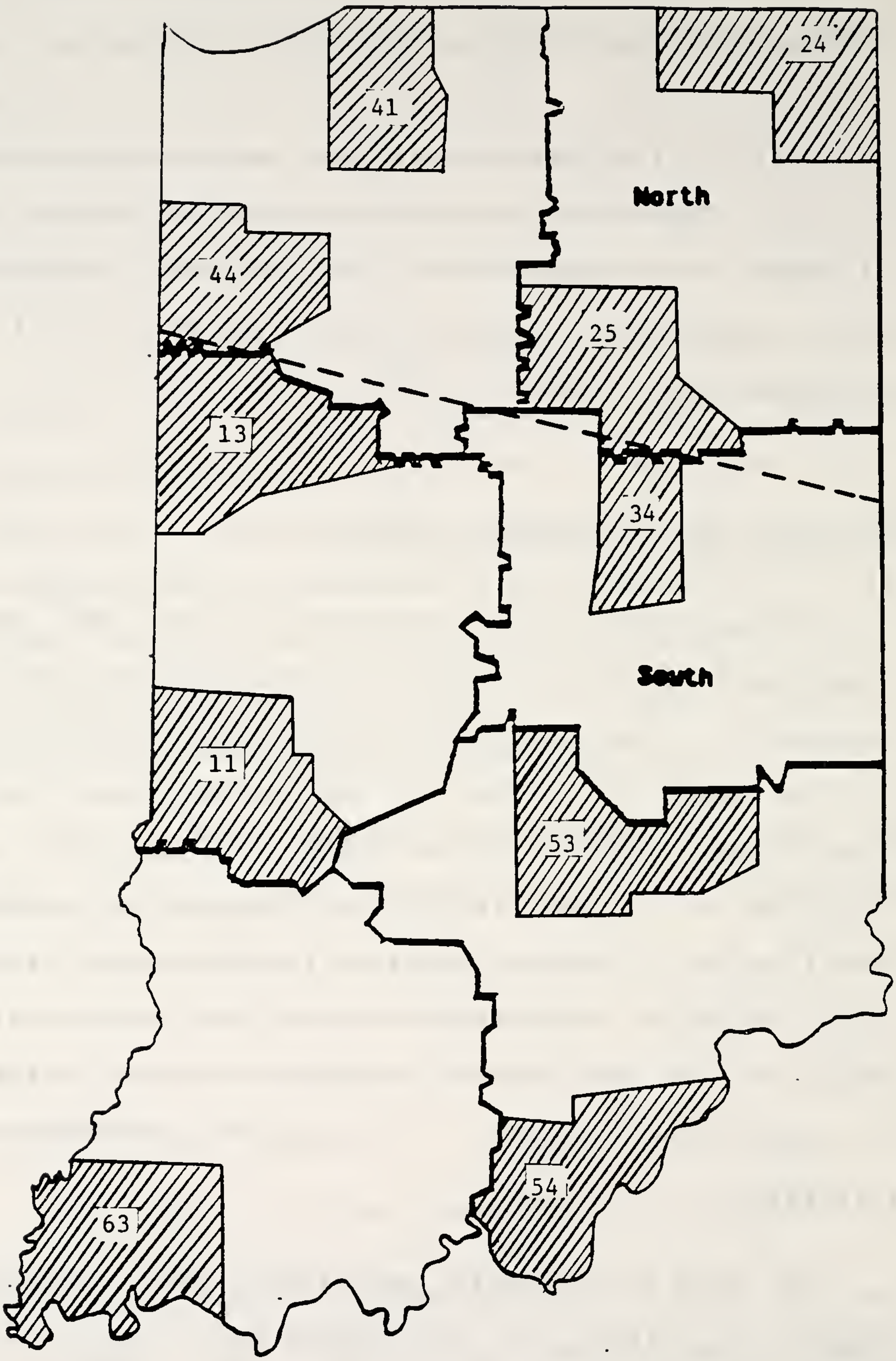


Figure 4.2 Locations of Subdistricts Included in the Study.

Table 4.2 Subdistricts Included in the Study.

Subdistrict	Code Number	District	Code Number	Region
Anderson	34	Greenfield	3	South
Angola	24	Fort Wayne	2	North
Columbus	53	Seymour	5	South
Fowler	13	Crawfordsville	1	South
Evansville	63	Vincennes	6	South
LaPorte	41	LaPorte	4	North
New Albany	54	Seymour	5	South
Rensselaer	44	LaPorte	4	North
Terre Haute	11	Crawfordsville	1	South
Wabash	25	Fort Wayne	2	North

"roughness files". Tables 4.3 and 4.4 show the distribution of the selected contract sections by highway class and pavement type in each subdistrict for the North and South regions. As shown in Table 4.3, two more subdistricts (Fort Wayne and Bluffton) were selected from the North region and only Interstate highways in these subdistricts were considered in order to augment the sample size, especially for overlaid pavements. A total of 550 contract sections were selected including 126 sections in Interstate and the remaining sections in Other State Highways (OSH).

4.5 Extraction of Routine Maintenance Quantities

The amount of routine maintenance applied between two dates of roughness measurements were determined from Crew Day Cards obtained from each subdistrict considered. A total of about ten thousand Crew Day Cards were analyzed. Cards with missing information, such as highway number, or county number of location of the work, were excluded.

The relevant information extracted from the Crew Day Cards included activity type, date of work, location of work, and the number of production units accomplished. The information was recorded in newly created "routine maintenance files".

Table 4.3 Distribution of the Selected Contract Sections in the North Region.

Subdistrict Name	Interstate Highways		Other State Highways					
			U.S.			S.R.		
	Rigid	Overlaid	Flexible	Rigid	Overlaid	Flexible	Rigid	Overlaid
Angola	–	4	–	1	7	24	1	6
LaPorte	6	–	5	8	14	11	4	5
Rensselaer	14	–	1	10	11	14	–	6
Wabash	–	6	4	6	6	21	3	8
Fort Wayne/Buffton[1]	–	8	–	–	–	–	–	–
Total	20	18	10	25	38	70	8	25

[1] Only Interstate Highways in these subdistricts were considered.

Table 4.4 Distribution of the Selected Contract Sections in the South Region.

Subdistrict Name	Interstate Highways		Other State Highways					
			U.S.			S.R.		
	Rigid	Overlaid	Flexible	Rigid	Overlaid	Flexible	Rigid	Overlaid
Anderson	4	12	-	-	-	12	1	14
Columbus	10	8	4	1	8	17	3	1
Evansville	10	-	-	4	10	15	20	5
Fowler	14	-	-	23	8	8	9	1
New Albany	14	6	3	1	-	18	6	3
Terre Haute	6	4	-	6	23	17	2	5
Total	58	30	7	35	49	87	41	29

4.6 Determination of Routine Maintenance Amount by Contract Sections

Both roughness and routine maintenance files have approximately the same inventory data which include the following information common to both files:

1. Highway Class and number
2. County number
3. Subdistrict number
4. District number

Using this information, it was possible to determine the amount of routine maintenance work done on a contract section. The contract sections usually also have recorded roughness measurements. Two location demarcation scales were established for each highway in each subdistrict. The first scale, called "contract section scale" used identified mile-posts and determined contract length in lane-miles. The second scale, called "landmarks scale", used mile-posts and the distance between two successive landmarks. Landmarks included intersections, bridges, county lines, and rivers.

Having established the two scales, routine maintenance quantity on each card was distributed according to the contract length by activity. In most cases, the location

of routine maintenance was recorded between landmarks containing more than one contract section. In such cases, the "landmarks scale" was applied and the routine maintenance work was distributed in proportion to the length of the different contract sections. If the location of a routine maintenance work was defined by mile-posts within a contract section, then the quantity of the work was assigned directly to the corresponding contract section. This occurred mainly with Interstate highways because they are mile-posted. Subjective judgment was used sometimes, especially when other factors were considered, such as pavement type and age.

Finally, the routine maintenance quantities were summed for each contract section and recorded along with roughness measurement and other information in a single file containing routine maintenance and roughness data.

4.7 Routine Maintenance Expenditure

Having determined the quantity of each routine maintenance activity on each contract section, the dollar values of maintenance activities performed on contract sections were obtained by multiplying the quantities by appropriate unit costs developed by Sharaf [10] and IDOH [62]. The routine maintenance expenditure was calculated

in dollars/lane-mile/year. The cost items considered were labor, materials, and the cost of motor fuel consumed by maintenance equipment and vehicles. These costs did not include overhead and equipment depreciation costs.

Table 4.5 presents the pavement routine maintenance activities included in the study and the corresponding unit costs. Cutting relief joints (Activity 209), joint and bump burning (Activity 214), and others (Activity 219) were not considered, because it was found that very few Crew Day Cards had these activities for the selected subdistricts during the study period.

4.8 Definition of Routine Maintenance Activities Included in the Study

There is a large amount of published material related to the application of pavement routine maintenance activities. The techniques for performing many of these activities are described in the Asphalt Institute Manual Series No. 16 [63]. The IDOH follows a set work procedures, as specified in the Field Operations Handbook [61]. As shown in Table 4.5, six pavement routine maintenance activities were included in this research. Shallow patching and crack sealing are discussed in depth in this section, because these activities constitute the major part of the

Table 4.5 Pavement Routine Maintenance Activities Included in the Study.

Activity Name	Code Number	Unit Cost[1] ($/P.U)[2]
Shallow Patching	201	114.17
Deep Patching	202	90.97
Premix Leveling	203	41.46
Seal Coating	205	1,352.60
Sealing Longitudinal Cracks and Joints	206	108.50
Sealing Cracks	207	290.00

[1]In 1985 Dollars

[2]Dollars/production Unit

total pavement routine maintenance expenditure in Indiana [9].

4.8.1 Shallow Patching (Activity 201)

Shallow patching is used to correct surface failures (potholes) of both concrete and bituminous pavements. Causes of surface failures are one or a combination of the following [63]:

1. Too little asphalt in the pavement.
2. Thin asphalt surface.
3. Failure of the base.
4. Poor drainage.

The material used in this activity can be either hot mix or cold mix patches. By definition, hot mix consists of a combination of aggregates uniformly mixed and coated with asphalt cement [64]. On the other hand, cold mix is a mixture of unheated mineral aggregate and emulsified or cutback asphalt [65]. Some subdistricts in Indiana stockpile an adequate amount of cold mix to last for one season. In most cases, the cold mix is placed in a porta-patcher (mechanism to heat mixes) and heated to approximately 150° to 200°F. Some superintendents consider

a heated cold mix to be the equivalent of a hot mix that is obtained from a plant [66]. A heated cold mix is not a hot plant mix, it is a hot emulsified mix.

Hot mix lasts longer because of increased workability which allows better compaction of the patch. Hot mix patches are usually placed during the period from April to October when the plants are in operation. This period also helps in producing patching with longer service life because of more favorable climatic and sub-surface conditions. The major cost of patching lies in placing the patch, not in the cost of the material [66]. So, proper training of maintenance personnel in the correct method of placing patches will result in higher productivity and longer service lives.

4.8.2 Deep Patching (Activity 202)

Deep patching is mainly used to repair high severity alligator cracks, shoving, shattering (blow up), and upheaval. It is a process of removing the surface and base as deep as necessary to reach firm support, extending at least a foot into good pavement outside the damaged area [63]. The amount of asphalt material used to prime the base should be only enough to knit together the top particles. The prepared edges of the surface surrounding

the area being patched should be tack coated to ensure a bond between them and the patch material. While for shallow patching, a light tack coat is enough to perform the work.

4.8.3 Premix Leveling (Activity 203)

Premix leveling or wedging involves placement of bituminous mixtures to correct different pavement distresses such as depressions, rutting, and corrugations. Premix leveling activity covers wider areas of pavement surface than shallow patching. Therefore, several subdistricts carry out this activity by contract rather than by IDOH personnel [27]. Premix leveling is usually applied using grader or paving machines.

4.8.4 Seal Coating (Activity 205)

There are several types of seal coat treatments including chip seals, sand seals, slurry seals, and fog seals. In general, seal coating is used to improve skid resistance and to correct different types of distresses such as low severity alligator cracks, shrinkage cracks, and raveling. The IDOH only uses chip seals and sand seals. Chip seal consists of coating full width roadway sections with hot bituminous material and covering with #11 or #12 stone. The cover aggregate in sand seal is sand rather than

stone. In Indiana, it was found that sand seals are not effective on poor pavement condition, but they are effective on pavement with fair or good condition [27]. Also, it was found that sand seals are not as effective as chip seals in treating pavement deficiencies.

4.8.5 Sealing Longitudinal Cracks and Joints (Activity 206)

Sealing longitudinal cracks and joints is accomplished by cleaning the cracks and joints and then filling them with liquid bituminous sealant. This activity prevents surface water seepage, protects joint fillers, and keeps out foreign matters [63]. The equipment used for sealing joints and cracks usually consists of truck or trailer mounted pressure applicators. Before any sealer is used, joints and cracks must be cleaned. The usual method of crack and joint cleaning is to use a stream of compressed air to blow out the accumulated debris. A router may be used as part of the cleaning process.

4.8.6 Sealing Cracks (Activity 207)

Crack sealing is a process of cleaning and sealing cracks in bituminous and concrete pavements as well as paved shoulders. The functions of aealing longitudinal cracks and joints (Activity 206) and sealing cracks

(Activity 207) and the procedures of applying these activities are similar but have some differences. For example, sealing cracks covers different types of cracks such as reflection cracks, transverse cracks, and block cracks, while Activity 206 covers mainly longitudinal cracks. Failure to seal cracks may result in pumping in concrete pavements and weakening of the base and subgrade in bituminous pavements.

Sealing cracks is usually performed in the cooler months, September through early December for two reasons. First, the cracks are wider in these months because of contraction of the pavements. Second, the cooler temperatures help to solidify the liquid bituminous sealant, thereby reducing the amount of material that flows out of the cracks. In a study performed at Purdue University [9], it was concluded that the level of expenditure in post-winter shallow patching is inversely proportional to the level of expenditure in pre-winter crack sealing. However, sealing cracks can only be effective as long as the sealant prevents the intrusion of water and dirt. In case of extensive cracking, the feasibility of seal coating or overlaying should be explored.

4.9 Evaluation of Routine Maintenance and Roughness Measurement Records in Indiana

4.9.1 Evaluation of Routine Maintenance Records

The IDOH has three levels of management involved in programming routine maintenance: the Central office, the District, and the Subdistrict. As mentioned in Section 4.2.1, the Crew Day Cards were considered the basic source of routine maintenance records in the development of the data base in the present study. As stated in the Field Operations Handbook of the Division of Maintenance of the IDOH [61], every Crew Day Card represents a certain amount of maintenance budget associated with one day of work on a particular activity. Therefore, filling these cards with the required information correctly and precisely would help not only in improving the accuracy of routine maintenance records but also in increasing the efficiency of the maintenance management program.

In the process of determining routine maintenance amount by contract sections, as described in Section 4.6, many difficulties were experienced. One of these difficulties was the lack of information about the exact location of maintenance work, and this occurred mainly with OSH because there are no mile-posts on these highways. Also, in many Crew Day Cards, the direction of the highway

where maintenance work was done was not mentioned. Furthermore, in case of multi-lane highways, many subdistricts, especially in the southern region, did not specify if the maintenance was applied on the inside or outside lane or on both. In general, it was found that the routine maintenance records in the northern region were more organized than in many subdistricts in the southern region. Also, the northern subdistricts provided more specific location of maintenance work on Crew Day Cards.

The routine maintenance records can be used effectively by improving the level of education and training of the crew members and the degree of supervision during maintenance work. This fact can be supported by the results of two studies [66,68] which were conducted at Purdue University to identify differences in productivity of routine maintenance among subdistricts. In these studies, it was found that the level of training of the crew members differed among subdistricts. Also, it was concluded that productivity of the crew on the job site was greater and the quality of maintenance work was better when the unit foreman was present at the job site.

To obtain accurate information on the location of maintenance work and in order to tie effectively routine maintenance records with roughness measurement records, the following information needs to be specified on the Crew Day

Cards:

1. Highway direction (northbound or southbound, eastbound or westbound).

2. In case of multi-lane highways, the lane which received maintenance work should be mentioned.

3. Pavement type (if it is flexible, rigid, or overlaid).

4. If the highway is mile-posted, the location of maintenance work should be specified between two successive mile-posts. If the highway is not mile-posted, maintenance location should be related to the nearest known landmark.

5. Pavement condition (wet or dry).

6. Presence of the unit foreman at the job site.

4.9.2 Evaluation of Pavement Roughness Measurements

The roughness of a pavement is the result of a chain of distress mechanisms and the combination of various modes of distress. Roughness is experienced by the vehicle, its operator, and any passengers or cargo. It is a phenomenon that results from the interaction of pavement surface profile and vehicles that travel over the surface. The IDOH

Division of Research collects roughness information on a periodic basis and this information is the only systematic pavement evaluation data available in Indiana. The discussion in this section involves the physical meaning of roughness number used in this study, brief description of the IDOH roughness equipment, and the accuracy of pavement roughness measurements and records.

4.9.2.1 PCA Roadmeter Roughness Measurements

Roughness testing is performed in Indiana with a PCA roadmeter. This device was developed by the Portland Cement Association in the early 1970s. It was based on the reasoning that road roughness should be measured in terms of the roughness felt by the vehicle occupants in order to provide a good correlation with PSI. The roadmeter is installed in a car assigned to the DRT. It is driven at 50 mph over the highway and the results are reported by mile and by contract section. The PCA roadmeter roughness number is computed as the square of the number of 1/8 inch movements of the car body with respect to the rear axle [69]. The unit of measurement used in this study is counts per mile.

4.9.2.2 IDOH Roughness Testing Equipment

In 1984, the IDOH Division of Research owned one Cox Model B, PCA roadmeter, which was mounted in a 1980 Ford Fairmont mid-size station wagon vehicle. The vehicle specification included a weight of 4350 lb., 225 cu. in. engine, coil springs on the front and rear, Monroe Matic shock absorbers, and C78 tire size.

In August, 1984, IDOH obtained a new Cox Model E, PCA roadmeter. This was installed in a new 1984 Ford LTD mid-size station wagon vehicle. This new vehicle had a gross weight of 4460 lb., 232 cu. in. engine, coil springs on the front and rear, Monroe Matic shock absorbers, and C78-14 tires.

The IDOH Division of Research developed a calibration procedure for the PCA roadmeter [57]. A sensitivity analysis was done on a number of factors that affect the measured roughness. These factors are: speed of vehicle, odometer calibration number, shock absorber type and temperature, tire type and pressure, displacement transducer spring tension, and fuel tank level. From the sensitivity analysis, a method was established for adjusting data that were collected when the roadmeter was not in the limits of the calibration. For example, it was found that higher speeds produce greater measured roughness

levels. For that reason, an equation for each vehicle type was developed that takes the roughness collected at 30 mph and converts it to a roughness that would have been found had it actually been tested at 50 mph. The developed adjustment equations are currently used by the DRT to correct the periodical roughness measurements of the entire highway system in Indiana.

4.9.2.3 Roughness Measurement Records

As described in Section 4.4, the data on roughness measurement on each contract section for 1984 and 1985 along with other information stated in Section 4.2.2 were obtained from the adjusted roughness computer files of the DRT. However, in some cases it was found that different items of information such as contract section number, year of construction or overlay, and pavement surface type were not recorded in these roughness files. In such cases, the Road Life Records of the IDOH Division of Planning were used to obtain the missing information. Also, the Road Life Records were used to obtain other information such as pavement surface thickness and pavement width, which are usually not available in the roughness computer files.

Furthermore, in the process of extracting roughness measurements and other related information from the

roughness measurements records, the following observations were made:

1. The period between the two roughness measurements (1984,1985) on the same contract section varied between 8 and 14 months. However, it was found that the average period for the same highway class or pavement type was about one year.

2. In some cases, although the contract section was longer than one mile, it was noticed that only one roughness reading was taken. This was mainly observed in OSH roughness records.

3. The Average Daily Traffic (ADT) values in the roughness files were for 1978.

4. In case of 2-lane , 2-way highways, it was found that roughness measurements were not taken on both lanes in the same year. In such cases, the available measurements were considered to be for both lanes.

5. It was noticed that, although no routine maintenance was applied during the study period, roughness measurements in 1985 for many contract sections were less than those in 1984. This may reflect not only the sensitivity of roughness measurement devices, but also the procedures of performing these measurements from

one year to another.

In order to use the DRT roughness measurement records as an efficient aid to district and central office personnel in making decisions regarding maintenance and resurfacing priorities, the above observations should be considered. Complete and systematic information on roughness measurements can serve effectively not only in relating pavement surface condition deterioration to routine maintenance expenditure level, but also in conducting future research in different areas.

4.10 Updating and Estimation of Traffic Data

Traffic data included traffic volume information, percentage of trucks, and the equivalent single axle load which is used as a common traffic index that accounts for different vehicle types and weights. The procedure used in this research to update and estimate traffic information is similar to the procedure followed by Sharaf and Sinha [9].

4.10.1 Average Daily Traffic

The ADT values were obtained from the traffic counts and studies performed by the IDOH Division of Planning. All 92 counties in Indiana were found to have complete

traffic maps for 1981-1985. Figure 4.3 is an illustration of such traffic maps.

In order to update traffic data, each pavement contract section was divided into one or more segments. These segments were determined on a basis of noticeable variation in the ADT value. The weighted average ADT value was computed for each contract section using Equation 4.1.

$$ADT = \frac{\Sigma ADT_j * L_j}{\Sigma L_j} \tag{4.1}$$

where,

ADT = average ADT value for a contract section.

ADT_j = ADT value of the jth segment within the contract section.

L_j = length of the jth segment within the contract section.

Knowing the 1981-1985 updated value of ADT for each contract section along with the 1978 ADT value which was obtained from the roughness files, the annual traffic growth rate (r) was computed for each contract section using Equation 4.2.

$$ADT_t = ADT_{78} * e^{(t-78)*r} \tag{4.2}$$

where,

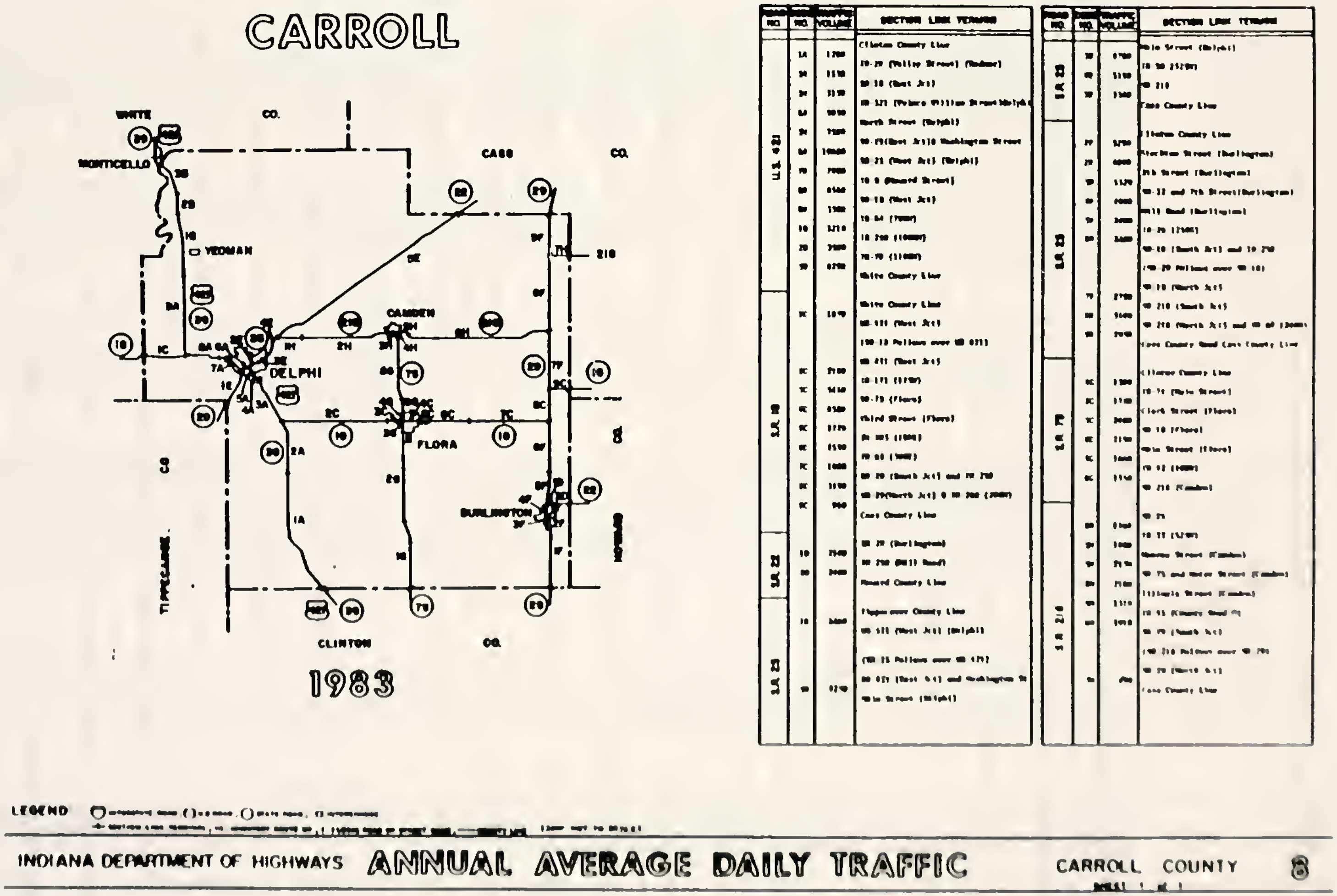


Figure 4.3 Example of a Traffic Map.

ADT_t = ADT in year t.

ADT_{78} = ADT in 1978.

r = annual ADT growth rate for years after 1978

t = 81, 82, 83, 84, 85.

In cases where the contract section crossed counties with different update years, the year of the update in the county containing the longest portion of the contract was considered in obtaining the annual ADT growth rate.

For the period preceding 1978, the 20-year growth rates developed by the IDOH Program Development Division for each county were found to be adequate for generating appropriate ADT values. These rates were developed based on actual traffic counts for rural and urban areas within each county for the period of 1955-1975. As shown in Table 4.6, these growth rates are for the entire county and these rates were applied to all contract sections within a particular county. If a contract section crossed county lines or rural/urban boundaries, a weighted average growth rate was considered. These growth rates along with those developed for the period of 1978-1985 cover the age range of most of the existing pavement contract sections. For sections constructed before 1955, the 20-year growth rates were applied. The 1978 ADT value and the appropriate growth rates were used to estimate the ADT value for any other year. Subsequently, the total volume of traffic for

Table 4.6 Twenty-Year(1955-1975) ADT Growth Rates.

20 YEAR FACTOR		URBAN	RURAL	20 YEAR FACTOR		URBAN	RURAL
1	Adams	1.535	1.337	47	Lawrence	1.460	1.383
2	Allen	1.662	1.494	48	Madison	1.625	1.416
3	Bartholomew	1.741	1.722	49	Marion	1.755	--
4	Benton	1.401	1.252	50	Marshall	1.484	1.397
5	Blackford	1.426	1.342	51	Martin	1.533	1.260
6	Boone	1.522	1.439	52	Miami	1.594	1.487
7	Brown	--	1.702	53	Monroe	1.837	1.792
8	Carroll	1.363	1.302	54	Montgomery	1.412	1.365
9	Cass	1.319	1.302	55	Morgan	1.750	1.655
10	Clark	1.740	1.659	56	Newton	--	1.323
11	Clay	1.334	1.261	57	Noble	1.607	1.401
12	Clinton	1.441	1.199	58	Ohio	--	1.308
13	Crawford	--	1.189	59	Orange	1.419	1.255
14	Daviess	1.360	1.258	60	Owen	--	1.353
15	Dearborn	1.483	1.314	61	Parke	1.461	1.188
16	Decatur	1.570	1.463	62	Perry	1.524	1.333
17	Dekalb	1.455	1.369	63	Pike	1.281	1.172
18	Delaware	1.653	1.468	64	Porter	1.890	1.750
19	Dubois	1.501	1.355	65	Posey	1.486	1.398
20	Elkhart	1.722	1.620	66	Pulaski	--	1.222
21	Fayette	1.479	1.386	67	Putnam	1.499	1.373
22	Floyd	1.474	1.473	68	Randolph	1.305	1.225
23	Fountain	1.526	1.198	69	Ripley	1.416	1.342
24	Franklin	1.473	1.325	70	Rush	1.347	1.275
25	Fulton	1.307	1.223	71	St. Joseph	1.760	1.466
26	Gibson	1.402	1.241	72	Scott	1.774	1.604
27	Grant	1.528	1.489	73	Shelby	1.568	1.509
28	Greene	1.354	1.293	74	Spencer	1.543	1.307
29	Hamilton	1.850	1.800	75	Starke	1.510	1.456
30	Hancock	1.881	1.806	76	Steuben	1.420	1.395
31	Harrison	1.643	1.430	77	Sullivan	1.258	1.165
32	Hendricks	1.775	1.650	78	Switzerland	--	1.140
33	Henry	1.461	1.374	79	Tippecanoe	1.687	1.465
34	Howard	1.775	1.650	80	Tipton	1.349	1.322
35	Huntington	1.351	1.283	81	Union	--	1.263
36	Jackson	1.545	1.379	82	Vanderburg	1.386	1.331
37	Jasper	1.494	1.425	83	Vermillion	1.242	1.166
38	Jay	1.328	1.229	84	Vigo	1.368	1.333
39	Jefferson	1.709	1.280	85	Wabash	1.483	1.353
40	Jennings	1.625	1.527	86	Warren	--	1.238
41	Johnson	1.850	1.755	87	Warrick	1.669	1.641
42	Knox	1.333	1.220	88	Washington	1.550	1.348
43	Kosciusko	1.695	1.578	89	Wayne	1.379	1.365
44	Lagrange	--	1.531	90	Wells	1.523	1.384
45	Lake	1.715	1.534	91	White	1.495	1.334
46	LaPorte	1.630	1.462	92	Whitley	1.453	1.436

each contract section was calculated from the following formula:

$$\text{Total Traffic} = \sum_{i=1}^{n} ADT_i * 365 \qquad (4.3)$$

where,

ADT_i = annual average daily traffic of the ith year.

n = pavement age (1985 - year opened to traffic).

4.10.2 Percentage of Trucks

Percentage of trucks (PTR) information should be known to convert the ADT value of a contract section to its corresponding Equivalent Single Axle Load (ESAL) applications. Based on the Federal Highway Administration (FHWA) vehicle classification study [70], number of trucks is defined as the summation of number of four major truck types: single unit truck; tractor semi-trailer combination; semi-trailer trailer; and truck and trailer. Important factors, such as highway system and location within a highway system, should be considered when determining the percentage of trucks. The following six highway systems were considered in the IDOH manual vehicle classification studies:

1. Federal Aid Interstate Rural

2. Federal Aid Interstate Urban

3. Federal Aid Primary Rural

4. Federal Aid Primary Urban

5. Federal Aid Secondary Rural

6. Federal Aid Secondary Urban

The procedure to obtain the percentage of trucks was similar to what Sharaf and Sinha used [9]. The earlier data base was augmented with information for 1983 and 1984. Table 4.7 shows the available counting locations along with the corresponding percentage of trucks for each highway system. As shown in this table, the change in percentage of trucks is small from year to year for the same location within a highway system. Also, percentage of trucks is significantly different from one highway system to another. In addition, percentage of trucks differs from location to location within the same highway system. Therefore, it was decided to consider the values for percentage of trucks separately for different locations even within the same highway system.

The counties that included one or more counting stations were considered first and the average percentage

Table 4.7 Updated Percentage of Trucks by Highway System by Location.

Highway System	Station Number	County Number	Percent of Trucks (PTR) 1978	1979	1980	1981	1983	1984	Average PTR
Interstate Rural	64	31	32	34	32	30	19	-	29.40
	164	26	39	-	35	-	-	-	37.00
	65	36	29	31	33	31	26	-	30.00
	165	45	27	31	26	29	32	-	29.00
	69	35	30	33	33	29	33	34	32.00
	70	89	34	39	36	34	33	-	35.20
	170	67	37	-	36	-	-	-	36.50
	270	30	33	-	39	-	36	37	36.25
	470	11	-	-	-	34	37	37	36.00
	74	15	20	26	25	21	27	20	23.17
	774	23	31	38	34	34	34	-	34.20
	94	64	29	30	27	24	29	-	27.80
		Avg[1]	30	32	32	29	30	32	30.83
Interstate Urban	565	49	8	-	8	-	8	-	8.00
	180	45	29	-	25	-	-	-	27.00
	865	22	-	-	-	22	11	10	14.30
	365	49	28	-	10	-	-	-	19.00
	465	49	12	-	10	-	-	-	11.00
		Avg[1]	18	-	15	22	10	10	15.00

Table 4.7 (Continued).

Highway System	Station Number	County Number	Percent of Trucks (PTR)						Average PTR
			1978	1979	1980	1981	1983	1984	
	41	45	19	-	20	-	18	-	19.00
	141	42	20	-	21	-	22	-	21.00
	43	54	-	12	-	-	-	-	12.00
	50	15	9	-	11	-	9	-	9.67
	250	36	-	-	-	8	-	-	8.00
	54	77	13	-	10	-	-	-	11.50
	56	19	15	-	16	-	14	-	15.00
Primary	256	58	-	8	-	-	-	-	8.00
Rural	66	82	-	-	-	5	-	4	4.50
	67	60	-	-	22	-	-	-	22.00
	3	70	-	15	-	-	-	-	15.00
	306	57	23	23	22	20	26	-	22.80
	406	20	29	-	25	-	28	-	27.33
	24	91	22	-	22	-	19	-	21.00
	30	2	28	30	27	25	26	26	27.00
	31	50	29	-	26	-	25	-	26.67
	32	68	-	-	8	-	8	-	8.00
	35	89	-	-	-	8	-	-	8.00
	137	55	-	-	12	11	12	-	11.67
	337	47	-	-	9	-	-	-	9.00

Table 4.7 (Continued).

Highway System	Station Number	County Number	Percent of Trucks (PTR)						Average PTR
			1978	1979	1980	1981	1983	1984	
	167	55	-	-	10	-	12	-	11.00
	135	31	8	-	8	-	-	-	8.00
	231	74	-	-	14	-	-	-	14.00
	531	79	-	-	-	13	13	-	13.00
Primary	237	62	-	-	13	-	-	-	13.00
Rural	621	66	18	-	22	-	19	-	19.67
	521	69	10	-	10	-	10	-	10.00
	421	46	-	-	13	-	10	-	11.50
	721	12	-	-	-	9	15	-	12.00
	235	88	-	-	-	15	-	-	15.00
		Avg[1]	19	21	16	13	16	15	16.67
	15	27	6	-	5	-	-	-	5.50
	124	2	-	16	-	-	-	17	16.50
	25	79	7	-	8	-	-	-	7.50
Primary	37	48	13	-	12	11	-	-	12.00
Urban	137	53	-	11	-	-	-	-	11.00
	83	82	21	21	20	21	20	-	20.60
	46	3	-	-	-	5	-	-	5.00
		Avg[1]	12	17	12	13	20	17	15.17

Table 4.7 (Continued).

Highway System	Station Number	County Number	Percent of Trucks (PTR) 1978	1979	1980	1981	1983	1984	Average PTR
	907	70	18	-	-	-	-	-	18.00
	13	43	7	9	9	-	7	-	8.00
	16	9	-	16	-	-	-	-	16.00
	131	3	7	-	6	-	6	-	6.33
	236	68	19	-	22	-	-	-	20.50
Secondary	40	67	9	11	8	10	9	-	9.40
Rural	140	30	5	-	6	-	5	-	5.33
	52	79	-	-	-	14	13	-	13.50
	136	54	5	-	7	-	7	-	6.33
	231	19	-	15	-	-	-	-	15.00
	446	53	5	-	6	-	-	-	5.50
	68	26	9	-	-	-	-	-	9.00
		Avg[1]	8	12	8	12	8	-	9.60
	431	36	-	-	-	5	6	-	5.50
Secondary	401	42	7	7	4	9	4	-	6.20
Urban	25	79	-	-	8	-	6	-	7.00
	62	22	4	4	3	-	-	-	3.67
		Avg[1]	5	7	5	6	5	-	5.60

[1] Average is weighted by mileage covered by each station

of trucks for a particular station within a highway system was assumed to apply to all contract sections belonging to the highway system. The counties with no counting stations were assigned values for percentage of trucks based on the similarity in location with other counties where counting stations are located. In cases where a contract section crossed county lines or rural and urban boundaries, the weighted average percentage of trucks was applied.

4.10.3 Equivalent Single Axle Load Applications

The Equivalent Single Axle Load (ESAL) for any year is a representation of the level of traffic using a pavement contract section. To take into consideration the effect of different vehicle types and weights, a common traffic index, 18-kip equivalent single axle load was used. The determination of the ESAL for a pavement section requires information on the ADT, vehicle type distribution, and the axle weight distribution for each vehicle type.

Based on the results of the IDOH truck weight studies, Sharaf and Sinha [9] developed Equivalent Axle Load Conversion Factors (EALF) for Interstate (Rural and Urban), OSH Rural, and OSH Urban. These factors are listed in Table 4.8 for rigid and flexible pavements. These conversion factors were used in the present research to compute the

Table 4.8 Equivalent Axle Load Conversion Factors (EALF). [9]

Year	Interstate		Other Rural		Other Urban	
	Rigid	Flexible	Rigid	Flexible	Rigid	Flexible
81	0.677	0.442	0.263	0.183	0.426	0.289
79	0.691	0.452	0.311	0.208	0.455	0.306
77	0.712	0.466	0.579	0.377	0.304	0.205
74	0.709	0.478	0.480	0.318	0.382	0.259
73	0.720	0.488	0.380	0.259	0.259	0.191
72	0.653	0.446	0.491	0.436	0.297	0.207
71	0.701	0.461	0.675	0.441	0.210	0.150
Average	0.695	0.462	0.450	0.317	0.333	0.230

annual ESAL. The ESAL value for a given year was calculated using Equation 4.4.

$$ESAL = ADT \times PTR \times EALF \times 365 \tag{4.4}$$

where,

ESAL = equivalent single axle load application for the year under consideration.

ADT = update average daily traffic for the year under consideration.

EALF = equivalent axle load conversion factor for the year under consideration.

PTR = average percent of trucks for the contract section.

Equation 4.4 was applied to rigid, flexible, and overlaid pavements for different years. Flexible pavements EALF were used to compute the ESAL for overlaid pavements. The average values of EALF, as shown in Table 4.8, were used to obtain the ESAL for years preceding 1971 and subsequent to 1981. The ESAL values for the individual years were summed to obtain the total accumulated ESAL during the pavement age. Finally, the updated traffic data along with other information such as year of construction or resurfacing, year of secondary surface, and surface thickness for each contract section were recorded in newly created "traffic and pavement characteristics files."

4.11 Data Base Illustration

The data base in the present study consisted of two major files. The first file included routine maintenance and roughness data. The second file included traffic and pavement characteristics data. The data base covered a total of 550 contract sections (126 in Interstate and 424 in OSH). For each contract section, the following items were recorded. Detailed information is given in Appendix A.

1. Pavement inventory data (data are common to both files):

   a. CON# - contract section number

   b. HWY - highway number

   c. D - highway direction code

      1. North

      2. South

      3. North and South (for two-lane highways)

      4. East

      5. West

      6. East and West (for two-lane highways)

d. T - highway type code

1. Interstate in the North region

2. Interstate in the South region

3. U.S. designated highway in the North region

4. U.S. designated highway in the South region

5. SR in the North region

6. SR in the South region

e. SD - subdistrict code number (see Table 4.2)

f. CO - county code number (see Table 4.6)

g. LM - contract section length in lane-miles

h. ST - pavement type code

1. flexible pavement

2. rigid pavement

3. rigid overlaid pavement

2. Routine maintenance and roughness data (see Table A.1)

a. PTCH - expenditure level of shallow and deep

patching (Activities 201 and 202) in \$/lane mile/year

b. SEAL - expenditure level of sealing longitudinal cracks and sealing cracks (Activities 206 and 207) in \$/lane mile/year

c. TOT - total expenditure level of all routine maintenance activities included in the study in \$/lane mile/year

d. RN84 - roughness measurement in 1984 (counts/mile)

e. RN85 - roughness measurement in 1985 (counts/mile)

f. P84 - Present Serviceability Index (PSI) in 1984

g. P85 - Present Serviceability Index (PSI) in 1985

3. Traffic and pavement characteristics data (see Table A.2)

a. YR - year of construction or resurfacing

b. YRS - year of secondary surface application (0 if none)

c. THIK - contract section surface thickness in inches

d. PTR - average percent of trucks

e. TOTADT - sum of annual average daily traffic values over the entire period of pavement age (Equation 4.3). To obtain the total value, the listed number should be multiplied by 365

f. ADT - mean annual average daily traffic

g. TESAL - total equivalent single axle load applications during the pavement age in thousands

h. ESAL - mean annual equivalent single axle load applications in thousands

CHAPTER 5

EFFECTS OF ROUTINE MAINTENANCE EXPENDITURE LEVEL ON RATE OF CHANGE IN PAVEMENT ROUGHNESS

5.1 Introduction

This chapter discusses the reason for using contract section instead of highway section as a pavement section unit in this research. Also included in this chapter is a covariance analysis performed to determine whether the data in both regions in Indiana can be analyzed as one data set or not. The conceptual basis developed in this research was then employed to study the effects of routine maintenance expenditure level on rate of change in pavement roughness as a measure of deterioration in pavement surface condition. Further analysis with respect to the effects of pavement age and traffic loading on maintenance effectiveness is presented in Chapter 6.

5.2 Reason for Using Contract Sections vs. Highway Sections

Pavement routine maintenance activities listed in

Table 4.5 were combined into three groups: (i) patching which consists of shallow patching (Activity 201) and deep patching (Activity 202); (ii) joint and crack sealing which consists of sealing longitudinal cracks and joints (Activity 206) and sealing cracks (Activity 207); and (iii) other activities consisting of premix leveling (Activity 203) and seal coating (Activity 205).

A comparison was made of the results using maintenance expenditure and roughness data on the basis of highway sections and contract sections. Ksaibati [71] examined the effect of routine maintenance expenditure on pavement roughness based on highway sections for Interstate highways (rigid and flexible). He observed that the rate of increase in roughness varied inversely with routine maintenance expenditure, but a significant statistical relationship could not be established because of the small sample size and the aggregation of routine maintenance data in terms of highway sections.

Since no data on flexible Interstate pavements were available in the present study, a comparison was made considering only rigid Interstate pavements in both regions. The routine maintenance expenditure data in terms of \$/lane-mile/year were considered and average values were computed based on contract sections and highway sections for 1984-1985 data. Figures 5.1 and 5.2 show respectively,

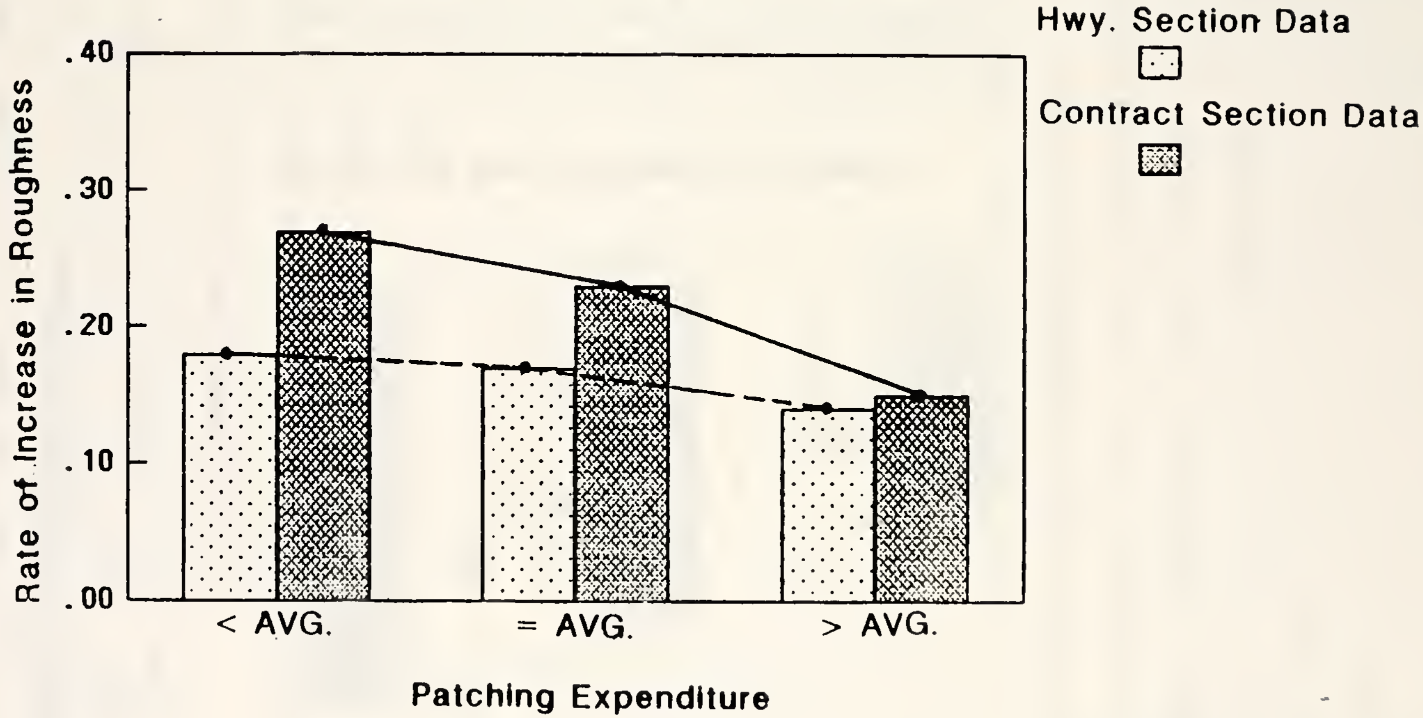


Figure 5.1 Effect of Patching Expenditure Level on Interstate Rigid Pavement Roughness.

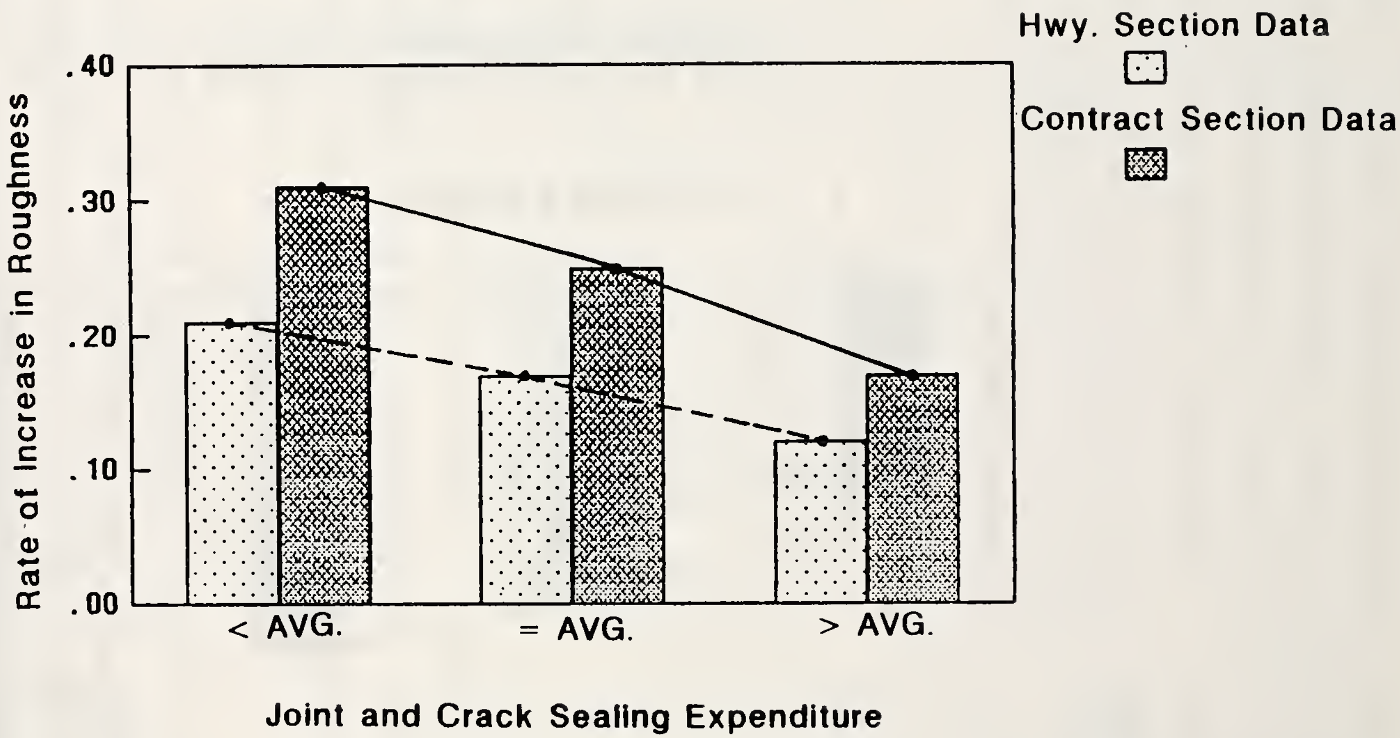


Figure 5.2 Effect of Joint and Crack Sealing Expenditure Level on Interstate Rigid Pavement Roughness.

the effect of patching and joint and crack sealing expenditure level on the rate of increase in pavement roughness. These figures indicate that, regardless of the level of aggregation of the data, the sections which received more than the average routine maintenance expenditure had a lower rate of increase in roughness than the ones which received less than average maintenance expenditure. Since the average expenditure level was not the same in two cases, the interest in this comparison is not to show the difference in the effect of each level of expenditure, but to show if the relationship can be improved using contract sections. In these figures, it is clear that the slope of the line using contract sections is more than that using highway sections. Hence, the statistical relationship between routine maintenance expenditure level and rate of change in pavement roughness improved when a smaller section unit was used. It should be noted that pavement sections indicating a decrease in surface roughness after routine maintenance were not included in this comparison.

The relative contribution of each group of maintenance to the total pavement maintenance expenditure is presented in Table 5.1. It is clear in this table that, regardless of pavement type, highway system or location, the portion of common pavement maintenance expenditure allocated to

Table 5.1 Percentage Distribution of Pavement Routine Maintenance Expenditure by Group of Maintenance:1984-1985.

Highway Class	R.M. Activities	North			South		
		Flexible	Rigid	Overlaid	Flexible	Rigid	Overlaid
Interstate	Patching	N.A.	46	46	N.A.	64	51
	Jt. & Crack Sealing	N.A.	54	54	N.A.	36	49
	Other Activities	N.A.	00	00	N.A.	00	00
Other State Highways	Patching	34	84	61	35	56	48
	Jt. & Crack Sealing	26	16	32	34	44	41
	Other Activities	40	00	7	31	00	11

patching and joint and crack sealing groups is considerably large. This portion was found to be 100% of the total pavement maintenance expenditure for Interstate highways and between 60% and 100% for Other State Highways in 1984-1985. Using the highway section data, Sharaf and Sinha [72] found this portion to be as high as 95% to 100% of the total pavement maintenance expenditure in the years 1980 - 1983. Thus, an accurate estimate of the effect of patching and joint and crack sealing on pavement roughness is likely to depict the effect of common pavement maintenance on pavement roughness.

5.3 Test to Combine the Data from North and South Regions

A statistical test was conducted to determine whether the data in both regions could be analyzed as one data set or not. The two southernmost subdistricts (54 and 63) were selected to be tested against the two northernmost subdistricts (24 and 41), as shown in Figure 4.1. Since sufficient Interstate sections were not available in these subdistricts, only Other State Highways were considered in the analysis. Pavement sections were grouped based on the type of routine maintenance applied during the study period. Table 5.2 shows the distribution of pavement contract sections by region and by routine maintenance category for each pavement type. The number of sections

Table 5.2 Distribution of Contract Sectiona by Region and by Routine Maintenance Category for Each Pavement Type.

Pavement Type	Routine Maintenance Category	Northern Region			Southern Region		
		Subdistricts		Total Data Points	Subdistricts		Total Data Points
		Angola (24)[1]	Laporte (41)[1]		New Albany (54)[1]	Evansville (63)[1]	
Flexible	Patching	10	9	19	11	4	15
	Patching and Jt. & Crack Sealing	5	1	6	4	10	14
	Jt. & Crack Sealing	1	1	2	2	1	3
	None	-	4	4	1	-	1
Rigid	Patching	2	8	10	6	4	10
	Patching and Jt. & Crack Sealing	-	3	3	-	12	12
	Jt. & Crack Sealing	-	-	-	-	8	8
	None	-	1	1	-	-	-
Overlaid	Patching	10	7	17	1	4	5
	Patching and Jt. & Crack Sealing	1	7	8	1	11	12
	Jt. & Crack Sealing	-	5	5	-	-	-
	None	-	-	-	-	-	-

[1] Code Number of Subdistrict.

that received joint and crack sealing or zero maintenance was very few and in some cells no observations were available. Therefore, it was decided to use two routine maintenance categories (patching and patching and joint and crack sealing) in the analysis.

To test preliminarily the effect of pavement age and traffic loading on pavement roughness, it was felt that these factors should be included in the analysis. Analysis of covariance technique was found to be the most suitable one in conducting this kind of test. Pavement age and cumulative Equivalent Single Axle Load (ΣESAL) were considered as quantitative variables and region and routine maintenance category as qualitative variables. Pavement roughness in 1985 was used as dependent variable. As recommended by Anderson [73] and in order to develop the covariance models for different pavement types, the following two tests were made on the dependent variables.

1. <u>Normality Test</u>: Since the number of observations in each of the considered cells was less than 50, Wilk-Shapiro [73] test was used. In some cases, the dependent variable was not found normally distributed even at the level of α = .01. So, $\log_{10}$ transformation was applied on the dependent variable and normality was indicated in all cases at α > .10.

2. <u>Homogeneity of Variances Test</u>: Since the number of observations was different from cell to cell (unbalanced design), the homogeneity of variances was checked by performing Burr-Foster (12) test. The variances of the dependent variable were found homogeneous at level of $\alpha = .01$ in all cases.

Having met the normality and homogeneity tests, the following covariance model was adopted.

$$\mathrm{Log}_{10}(RN_{85}) = \mu + R + RM + R*RM + Age + \Sigma ESAL + \varepsilon \quad (5.1)$$

where,

RN_{85} = roughness measurement in 1985 in counts/mile

μ = overall mean of the dependent variable

R = region (0 = North; 1 = South)

RM = routine maintenance category (2 = patching; 3 = patching and joint and crack sealing)

R*RM = interaction between region and routine maintenance category

Age = pavement age since construction or last resurfacing in years

ΣESAL = total accumulated ESAL in thousands

ε = random error component

Table 5.3 shows the statistical characteristics of covariance analysis for each pavement type. The major

Table 5.3 Statistical Characteristics of Covariance Analysis by Pavement Type.

Variables	Flexible Pavements 54[1]		Rigid Pavements 35[1]		Overlaid Pavements 42[1]	
	F-Value	α-Level	F-Value	α-Level	F-Value	α-Level
Region	3.70	0.060	4.02	0.054	5.66	0.023
RM	0.15	0.702	0.36	0.551	0.15	0.701
Region*RM	1.61	0.211	6.19	0.019	2.48	0.124
Age	19.06	0.000	0.94	0.341	4.52	0.040
ΣESAL	2.69	0.108	0.07	0.796	4.48	0.041

[1] Number of Observations.

findings of this analysis are summarized below.

1. The regional effect was significant in all cases at level of $\alpha < .10$. Based on this finding, regression models were developed in the next section, and regional effect was considered as a main factor in these models.

2. Routine maintenance category (RM) was found to be not significant with respect to roughness measurements in 1985. However, the interaction between region and routine maintenance category was significant at $\alpha <$ .25. This level of α was chosen because the recording of the location of routine maintenance work in most of the Crew Day Cards was not precise. In addition, the initial data analysis was conducted as an overall test. Regression models were developed in Section 5.4 to specify the trend of this interaction. The significance of the interaction between region and routine maintenance category implied that effects of RM category probably differed between North and South regions.

3. The effects of pavement age and ΣESAL were significant at $\alpha < .10$, except for rigid pavements. A part of the reason can be that most rigid pavement sections in the sample were very old in both regions.

The above conclusions cannot be generalized because the analysis was conducted with only 4 out of 10 subdistricts in the data base.

5.4 Regression Models for Routine Maintenance Expenditure and Regional Effects

Based on the results of the covariance analysis, a regression analysis was performed to study the effects of routine maintenance expenditure level and region on pavement roughness. To determine whether the relationship between routine maintenance expenditure level and pavement roughness was statistically improved by using contract sections instead of highway sections, rate of change in pavement roughness was used as the dependent variable in these models. Pavement sections with both negative and positive changes in roughness were considered in the analysis. Rate of change in pavement roughness was calculated as follows:

$$RRN = \frac{RN_{85} - RN_{84}}{RN_{84}} \qquad (5.2)$$

where,

RRN = rate of change in pavement roughness

RN_{84} = roughness measurement in 1984 (counts/mile)

RN_{85} = roughness measurement in 1985 (counts/mile)

Since Pavement Serviceability Index (PSI) is highly correlated to pavement roughness, RRN as described in Section 3.5, can be used as a measure of deterioration in pavement surface condition. In Equation 5.2, (RN_{84}) can be assumed to represent the cumulative effect of past maintenance on pavement condition, while (RN_{85}-RN_{84}) represents the effect of routine maintenance that was applied between the two roughness measurements, assuming all other factors remaining the same during the period.

The analysis included data from all the selected subdistricts in both regions. Only those pavement sections that received Patching (P) or Patching and Joint & Crack Sealing (PS) were analyzed. PS symbol means Patching and Crack Sealing in case of flexible and overlaid pavements. Pavement sections with only one roughness reading or pavement sections that did not receive any routine maintenance were not considered in the analysis. Five categories of highway class - pavement type were included: Interstate rigid pavement; Interstate overlaid pavement; OSH flexible pavement; OSH rigid pavement; and OSH overlaid pavement. Three criteria were considered in selecting the best model [74]: (i) the general goodness-of-fit represented by the coefficient of multiple determination (R^2); (ii) the general linearity test for the model through

the application of the general F-test and (iii) the significance of individual coefficients of the model through the t- or F-tests. These criteria were applied and an attempt was made to have the same model type for the five categories in order to facilitate the consideration of the effects of different factors.

After several trials, the following regression model appeared to satisfy most of the required conditions.

$$RRN = a + b \operatorname{Log}_{10} (RM) + c (R) + d \operatorname{Log}_{10} (RM) * (R) \tag{5.3}$$

where,

RRN = rate of change in pavement roughness

RM = routine maintenance expenditure level ($/lane-mile/Year). This variable takes the symbol (P) for pavement sections that received patching and (PS) for sections that received patching and joint and crack sealing.

R = dummy variable to represent the region in which the pavement section is located: 0 for northern region and 1 for southern region.

a,b,c,d = regression parameters.

The following regression models were found significant at $\alpha = .05$.

For Interstate rigid pavements:

$$RRN = 1.0 - 0.37 \; Log_{10} \; (PS) - 0.07 \; R \qquad (5.4)$$

For Interstate overlaid pavements:

$$RRN = 1.83 - 0.81 \; Log_{10} \; (PS) + 0.11 \; R \qquad (5.5)$$

$$RRN = 0.27 - 0.20 \; Log_{10} \; (P) + 0.26 \; R \qquad (5.6)$$

For OSH flexible pavements:

$$RRN = 1.5 - 0.49 \; Log_{10} \; (PS) + 2.19 \; R - 0.79 \; Log_{10} \; (PS) * R \qquad (5.7)$$

$$RRN = 1.65 - 0.65 \; Log_{10} \; (P) - 0.94 \; R + 0.43 \; Log_{10} \; (P) * R \qquad (5.8)$$

For OSH overlaid pavements:

$$RRN = 5.44 - 2.04 \; Log_{10} \; (PS) - 3.8 \; R + 1.5 \; Log_{10} \; (PS) * R \qquad (5.9)$$

For OSH rigid pavements:

$$RRN = 0.62 - 0.15 \; Log_{10} \; (P) - 0.13 \; R \qquad (5.10)$$

Only Equations 5.7, 5.8, and 5.9 included the interaction term (between routine maintenance expenditure level and region). This is probably because the routine maintenance expenditure level on OSH had a wider range. For example, the expenditure level of PS on OSH overlaid

pavements varied between \$100 and \$750/lane-mile/year, while on Interstate overlaid it varied between \$150 and \$400/lane-mile/year.

A summary of the characteristics of the regression models are given in Tables 5.4 and 5.5, respectively. As shown in these tables, a relatively higher R^2 was obtained for Interstate than OSH models. This may be due to the fact that Interstate highways are mile posted; so, it was easier and more accurate to match routine maintenance locations with roughness measurements. Furthermore, the significance test for the coefficient b for the variable RM (routine maintenance expenditure level) showed a high level of confidence. The levels of significance of the region and interaction term were lower than that of the expenditure level. However, these variables could be considered significant at 90% level of confidence as shown in Tables 5.4 and 5.5.

Two observations can be made regarding the insignificant models: (i) number of available sections in the northern region in some cases was very small and (ii) routine maintenance records included in the study in southern region were less organized and the location of maintenance on these records was less accurate. Therefore, regression models were developed separately for northern and southern regions. Table 5.6 shows these statistical

Table 5.4 Statistical Characteristics of Patching and Joint and Crack Sealing (PS) Models.

Criterion	Interstate Rigid	Interstate Overlaid	OSH Flexible	OSH Rigid	OSH Overlaid
Number of Observations	27	10	44	43	57
Coefficient of Determination (R^2)	0.30	0.86	0.46	0.07	0.32
Adjusted Coefficient (adj. R^2)	0.27	0.84	0.43	0.05	0.30
Linearity Test					
F-Value	5.14	20.96	11.23	1.48	8.37
α Level	0.014	0.001	0	0.24	0
Significance Test for Coefficients					
Log_{10} (PS)					
F-Value	9.78	23.06	3.66	2.95	14.82
α Value	0.005	0.002	0.063	0.093	0
Region					
F-Value	1.15	7.71	6.20	0	7.86
α Value	0.29	0.028	0.017	0.95	0.007
Log_{10} (PS) Region					
F-Value	--	--	5.24	--	7.27
α Value	--	--	0.027	--	0.009

Table 5.5 Statistical Characteristics of Patching (P) Models.

Criterion	Interstate Rigid	Interstate Overlaid	OSH Flexible	OSH Rigid	OSH Overlaid
Number of Observations	29	21	78	44	47
Coefficient of Determination (R^2)	0.13	0.61	0.21	0.25	0.09
Adjusted Coefficient (adj. R^2)	0.06	0.59	0.18	0.23	0.07
Linearity Test					
F-Value	1.20	14.07	6.33	6.70	2.07
α Level	0.33	0	0.001	0.003	0.14
Significance Test for Coefficients					
$\log_{10}$ (P)					
F-Value	1.27	10.88	16.17	6.37	3.71
α Value	0.27	0.004	0	0.02	0.061
Region					
F-Value	1.20	18.49	3.87	3.94	0.57
α Value	0.28	0	0.053	0.05	0.45
$\log_{10}$ (P) Region					
F-Value	1.26	--	3.12	--	--
α Value	0.27	--	0.082	--	--

Table 5.6 Statistical Models for the Effect of Routine Maintenance Expenditure Level by Region.

Routine Maintenance Variable	Pavement Type	Northern Region Model	Northern R^2	Northern Adj. R^2	Southern Region Model	Southern R^2	Southern Adj. R^2
Patching and Joint and Crack Sealing	Interstate Rigid	$RRN=1.14-0.43\ Log_{10}(PS)$	0.50	0.46	$RRN=0.79-0.30\ Log_{10}(PS)$	0.15	0.06
	Interstate Overlaid	$RRN=2.2-.97\ Log_{10}(PS)$	0.94	0.90	$RRN=1.63-.63\ Log_{10}(PS)$	0.63	0.54
	OSH Flexible	$RRN=1.5-0.49\ Log_{10}(PS)$	0.21	0.17	$RRN=3.68-1.28\ Log_{10}(PS)$	0.53	0.51
	OSH Rigid	$RRN=0.65-0.10\ Log_{10}(PS)$	0.05*	-0.03	$RRN=1.45-0.43\ Log_{10}(PS)$	0.08*	0.05
	OSH Overlaid	$RRN=5.44-2.04\ Log_{10}(PS)$	0.42	0.38	$RRN=1.63-0.54\ Log_{10}(PS)$	0.24	0.22
Patching	Interstate Rigid	$RRN=5.1-2.3\ Log_{10}(P)$	0.99	0.99	$RRN=0.27-0.05\ Log_{10}(P)$	0.02*	-0.02
	Interstate Overlaid	$RRN=0.47-0.31\ Log_{10}(P)$	0.47	0.42	$RRN=0.43-0.15\ Log_{10}(P)$	0.38	0.29
	OSH Flexible	$RRN=1.64-0.65\ Log_{10}(P)$	0.28	0.26	$RRN=0.70-0.23\ Log_{10}(P)$	0.05*	0.02
	OSH Rigid	$RRN=0.65-0.16\ Log_{10}(P)$	0.33	0.28	$RRN=0.46-0.13\ Log_{10}(P)$	0.08*	0.04
	OSH Overlaid	$RRN=0.86-0.29\ Log_{10}(P)$	0.11	0.07	$RRN=0.65-0.23\ Log_{10}(P)$	0.03*	-0.02

* The model is not significant at $\alpha = .10$.

models. As shown in this table, in general, higher R^2 was obtained for all category models in the North. Most of the category models in the southern region were not significant at $\alpha = 0.10$. A possible reason of these results is the inaccuracy in determining the exact location and amount of maintenance activities.

5.5 Implications of Routine Maintenance Expenditure Level Effect Models

The effects of routine maintenance expenditure level and region on rate of change in pavement roughness can be best demonstrated through the examination of the graphical presentations in Figures 5.3 to 5.8. The RRN was positive in most cases indicating that roughness increased regardless of maintenance expenditure level. However, the amount of this increase varied. It is clear that in most of the cases, RRN in the northern region was higher than that in southern region, especially at low expenditure level of routine maintenance. This may be because of longer cold period and higher amount of snowfall in the northern region requiring a higher level of maintenance. The validity of this conclusion can be supported by the fact, as reported by Fwa and Sinha [12], that the non-load-related damage responsibility in the northern region is significantly higher than that in the southern region.

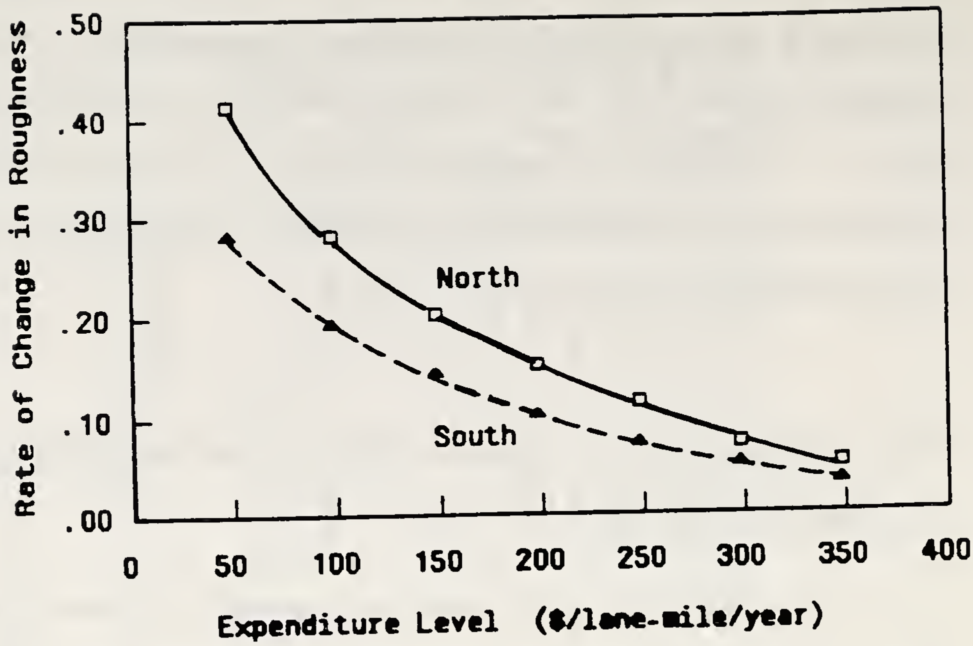


Figure 5.3 Estimated Effect of Patching and Joint and Crack Sealing (PS) Expenditure Level on Interstate Rigid Pavement Roughness (Equation 5.4).

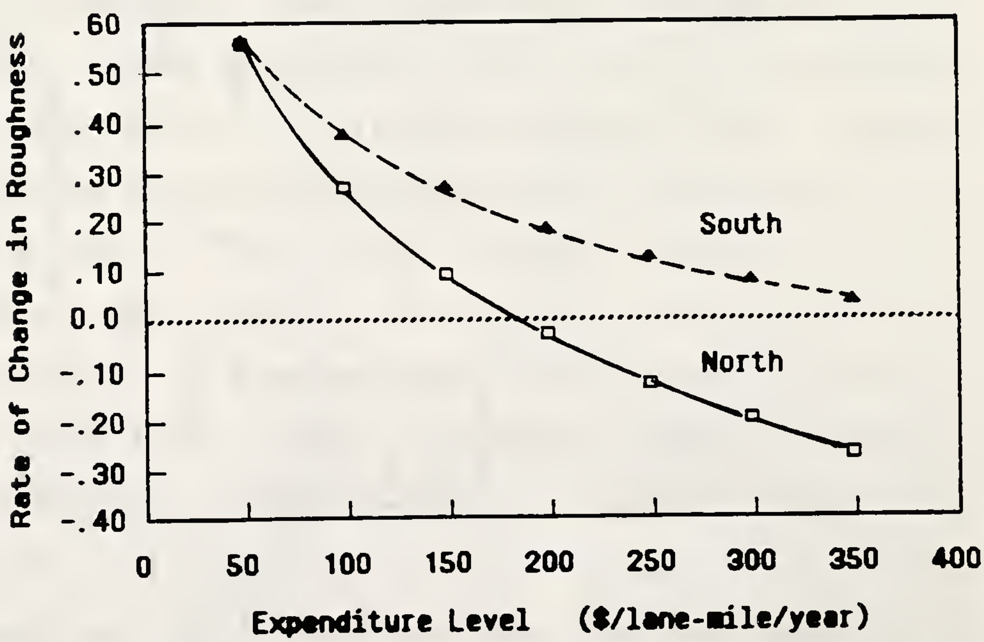


Figure 5.4 Estimated Effect of Patching and Crack Sealing (PS) Expenditure Level on Interstate Overlaid Pavement Roughness (Equation 5.5).

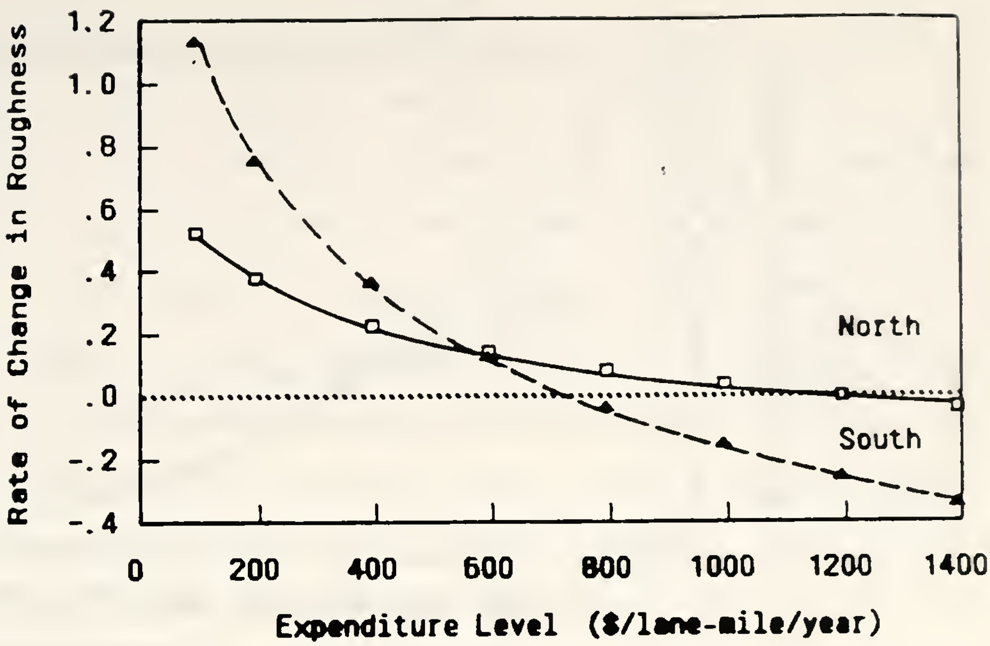


Figure 5.5 Estimated Effect of Patching and Crack Sealing (PS) Expenditure Level on OSH Flexible Pavement Roughness (Equation 5.7).

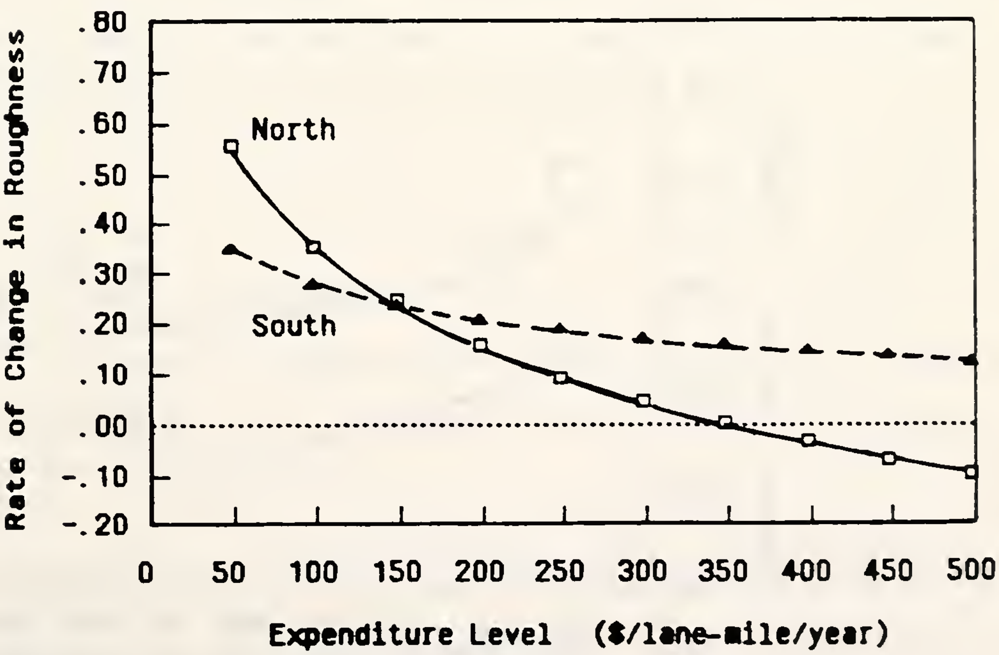


Figure 5.6 Estimated Effect of Patching (P) Expenditure Level on OSH Flexible Pavement Roughness (Equation 5.8).

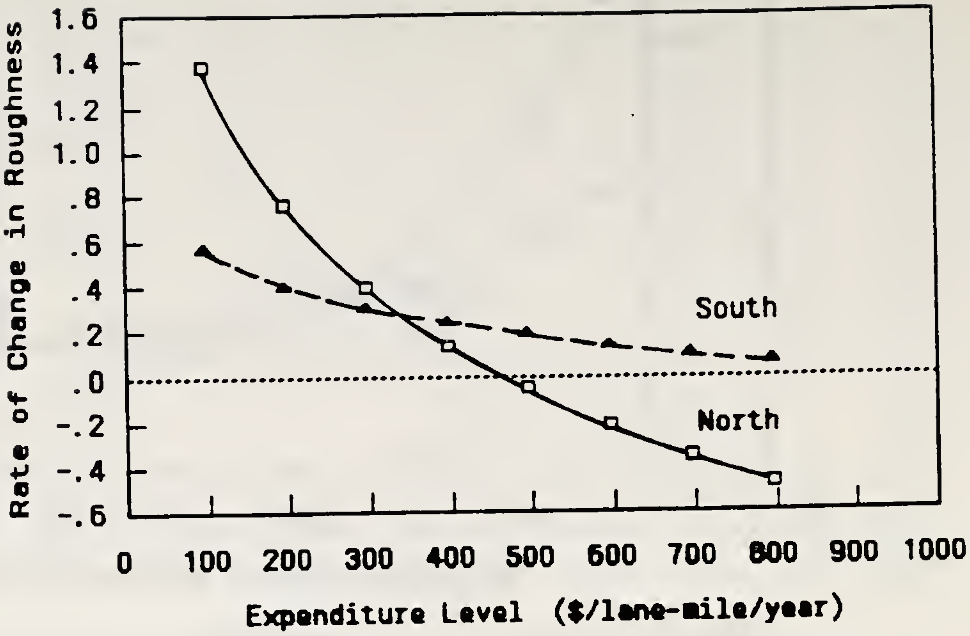


Figure 5.7 Estimated Effect of Patching and Crack Sealing (PS) Expenditure Level on OSH Overlaid Pavement Roughness (Equation 5.9).

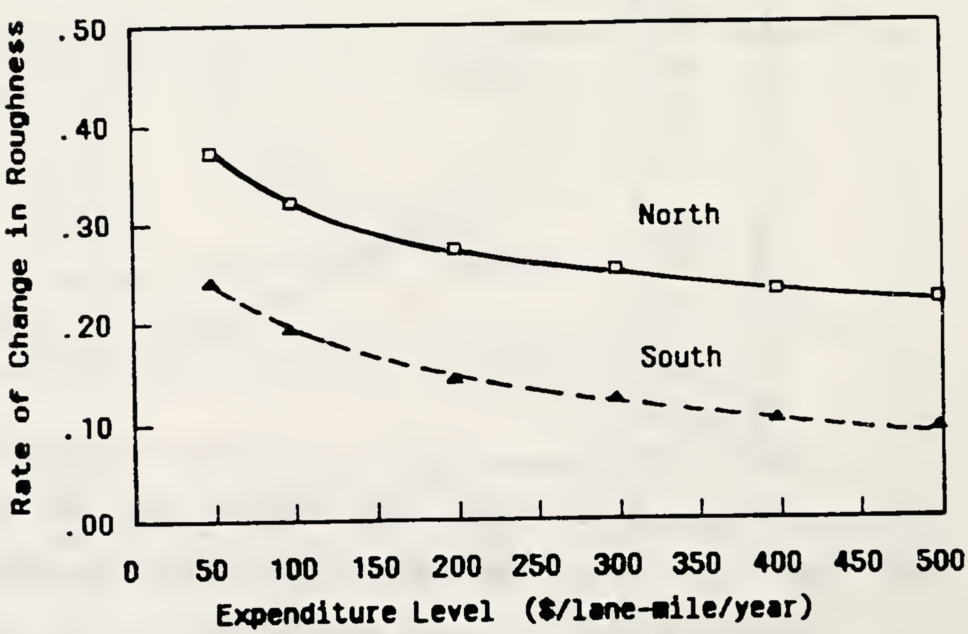


Figure 5.8 Estimated Effect of Patching (P) Expenditure Level on OSH Rigid Pavement Roughness (Equation 5.10).

In some cases, as shown in Figures 5.4 and 5.5, RRN is higher in the southern region. In these cases, it was found that the average pavement age of the analyzed sections in the southern region was more and the average ESAL on these sections was also higher. For example, the average age of OSH flexible pavement sections in the southern region that received patching and sealing was about 12 years while it was 9 years in the northern region. The corresponding average traffic loading levels were 209,000 and 151,000 accumulated ESAL, respectively.

It is obvious in Figures 5.3 to 5.8, that as routine maintenance expenditure level increased, RRN decreased and the difference in pavement surface deterioration between the two regions became less. In some cases, as shown in Figures 5.6 and 5.7, at higher expenditure levels RRN in the northern region was lower than that in southern region. In some cases, in the North, pavement roughness decreased even at lower expenditure levels. These results may possibly reflect the higher maintenance quality and degree of supervision in the subdistricts selected in the northern region.

The discussion of the results in this chapter leads to the concept of routine maintenance cost-effectiveness. Maintenance cost-effectiveness, as explained in Section 3.6, has been considered in this study in terms of the

reduction in RRN associated with an increase in maintenance expenditure. In general, the reduction in RRN in the northern region was more than that in the southern region for a given increment of maintenance expenditure, regardless of pavement type or maintenance activity. Furthermore, at low levels of maintenance expenditure, an increase in expenditure would cause a greater reduction in RRN. For example, as shown in Table 5.7, if PS expenditure level increased from \$50 to \$100/lane-mile/year, the reduction in RRN for Interstate overlaid in the northern and southern regions were 0.29 and 0.19, respectively. In contrast, if PS expenditure level increased from \$200 to \$250/lane-mile/year, the corresponding reduction values in RRN were 0.10 and 0.06, respectively.

A main conclusion that can be drawn is that maintenance cost-effectiveness is higher in the northern region than that in the southern region. This result is consistent with what Fwa and Sinha [75] observed in an earlier study. They stated that the amount of pavement damage repaired (i.e. the amount of PSI-ESAL loss recovered) per dollar worth of maintenance work was greater in the northern region.

The concept of maintenance cost-effectiveness can be used to compare the effect of same maintenance activity expenditure level on surface roughness of different

Table 5.7 Estimated Reduction in Rate of Change in Pavement Roughness as Routine Maintenance Expenditure Level Changes for Interstate - Overlaid.

Increase in Expenditure Level ($/lane-mile/year)	Reduction in Rate of Change in Pavement Roughness			
	Patching and Crack Sealing (PS)		Patching (P)	
From To	North	South	North	South
50 - 100	0.29	0.19	0.09	0.05
100 - 150	0.17	0.11	0.05	0.03
150 - 200	0.12	0.08	0.04	0.02
200 - 250	0.10	0.06	0.03	0.01
250 - 300	0.07	0.05	0.03	0.01
300 - 350	0.07	0.04	0.02	0.01

pavement types. Table 5.8 shows the effect of changes in patching expenditure level on reduction in RRN for OSH flexible and rigid pavements. If patching expenditure level increased from $50 to $100/lane-mile/year, the reduction in RRN for OSH flexible and rigid pavement in the northern region were 0.20 and 0.05, respectively. In general, it was found that regardless of region, highway class or maintenance activity, the response of rigid pavement to changes in expenditure level was less than that of flexible or overlaid pavements.

Figures 5.9 and 5.10 show the effect of expenditure level of two maintenance categories (P and PS) on RRN for Interstate overlaid and OSH flexible pavements in the southern region, respectively. It is clear in these figures that regardless of highway class or pavement type, the sections receiving patching and crack sealing had a higher cost-effectiveness than those receiving only patching. As the data were not collected in a controlled experiment, it cannot be conclusively stated that crack sealing adds to the effectiveness of maintenance expenditure. However, the analysis suggests such a possibility.

An important application of the results of this analysis is in assessment of the effect of region, routine maintenance expenditure level and their interaction on

Table 5.8 Estimated Effect of Changes in Patching Expenditure Level on Reduction in Rate of Change in Pavement Roughness for Two Pavement Types.

Increase in Expenditure Level ($/lane-mile/year)	Reduction in Rate of Change in Pavement Roughness			
	OSH - Flexible		OSH - Rigid	
From - To	North	South	North	South
50 - 100	0.20	0.07	0.05	0.05
100 - 150	0.11	0.04	0.03	0.03
150 - 200	0.09	0.03	0.02	0.03
200 - 250	0.06	0.02	0.01	0.01
250 - 300	0.05	0.02	0.01	0.01
300 - 350	0.04	0.01	0.01	0.01
350 - 400	0.04	0.01	0.01	0.01

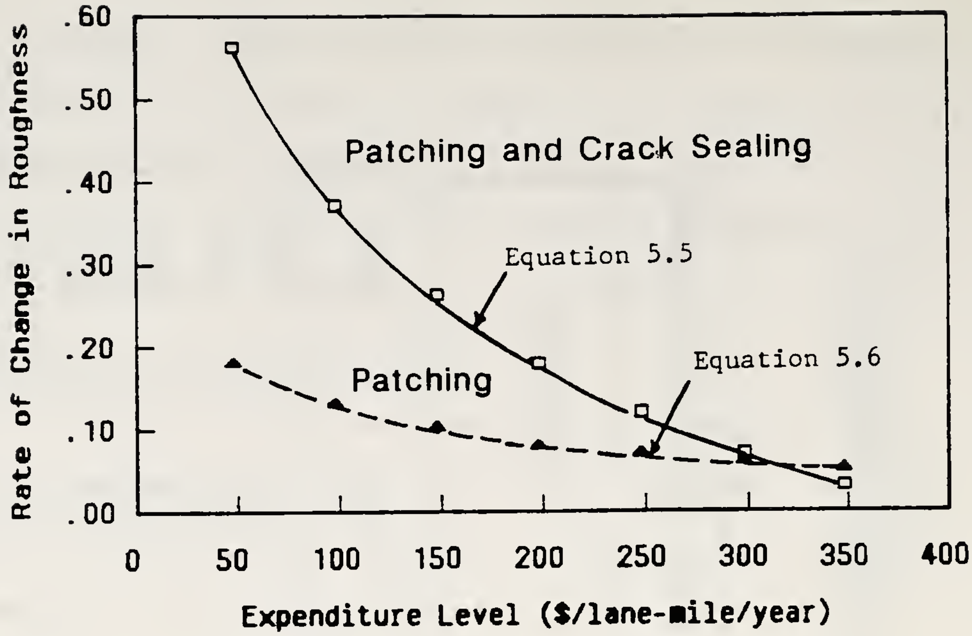


Figure 5.9 Estimated Effect of Expenditure Level of Two Maintenance Policies on Interstate Overlaid Pavement Roughness in the Southern Region.

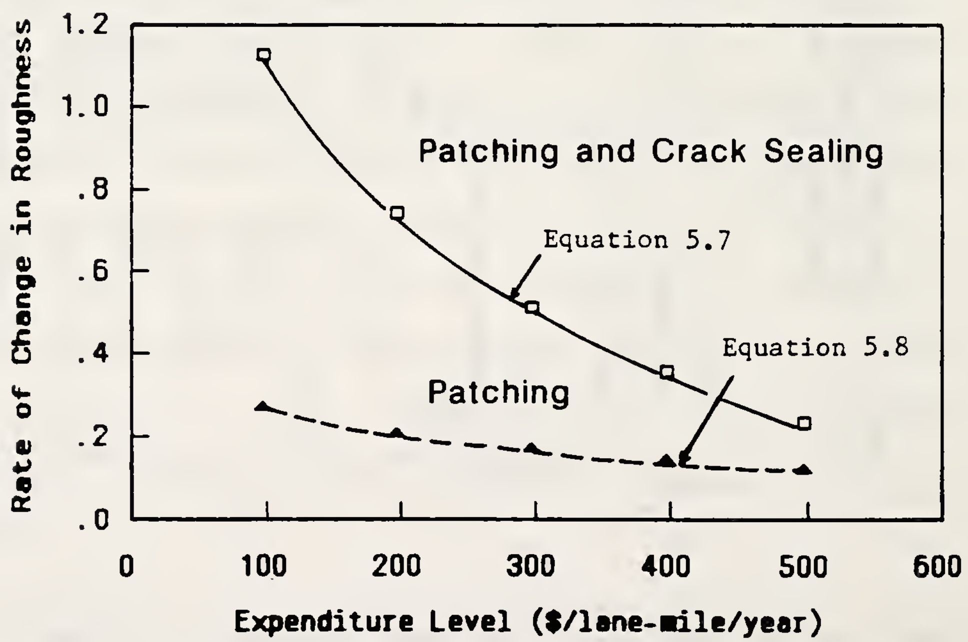


Figure 5.10 Estimated Effect of Expenditure Level of Two Maintenance Policies on OSH Flexible Pavement Roughness in the Southern Region.

pavement performance in terms of surface roughness. The results can be used to help the maintenance management group at the IDOH Central Office monitor the surface condition of the highway network within a subdistrict on a periodic basis. In addition, knowing the surface roughness of pavement sections, the models can be used by maintenance managers to estimate the required increase in maintenance expenditure level in order to achieve a specified level of improvement in overall pavement condition. It should be noted, however, that these models do not conclusively describe the relationship between rate of change in roughness and routine maintenance expenditure level since the statistical significance was not always high.

5.6 Chapter Summary

As a result of a covariance analysis it was found that the effect of region on pavement roughness was significant in all cases at $\alpha < .10$. Therefore, regression models for the effect of routine maintenance expenditure level on rate of change in pavement roughness were developed and the region was considered a main factor in these models. The use of smaller pavement section units (contract section) improved statistical relationship between routine maintenance expenditure level and pavement roughness, and the effect of expenditure level was found significant in

most of the developed models.

It was observed that the rate of change in pavement roughness was more in the northern region especially at low expenditure levels. The results reflect not only the possible effect of maintenance quality but also the importance of organizing and classifying the maintenance records as noticed in the northern region. Furthermore, it was found that the sections receiving patching and joint and crack sealing had higher cost-effectiveness than the sections receiving patching alone. However, because the data were not obtained through controlled experiments and sample sizes were limited, the results cannot be considered conclusive.

CHAPTER 6

EVALUATION OF THE EFFECTS OF PAVEMENT AGE AND TRAFFIC LOADING ON MAINTENANCE EFFECTIVENESS

6.1 Introduction

In the conceptual basis for assessing routine maintenance effects, presented in Chapter 3, two measures of deterioration in pavement surface condition were used: rate of change in pavement roughness (RRN) and change in pavement roughness (ΔRN). Regression models were developed to examine the effect of routine maintenance expenditure level on rate of change in pavement roughness, but most of these models had low R^2. Other factors, such as pavement age and traffic loading, were not introduced in the models, because the effects of these factors on RRN were considered to be implicitly included in roughness measurements. Direct effects of pavement age and traffic loading on pavement condition can be represented by using ΔRN as a measure of deterioration in pavement surface condition.

6.2 Statistical Analysis by Routine Maintenance Category

6.2.1 Definitions of Routine Maintenance Categories Included in the Analysis

The regression models developed in Chapter 5 included only two routine maintenance categories: Patching (P) and Patching and Joint and Crack Sealing (PS). The effects of other activities, such as premix leveling and seal coating, were not analyzed, because they were considered in the proposed methodology as an interface between basic routine maintenance and resurfacing activities. They are usually performed periodically, not annually. So, the effect of premix leveling or seal coating expenditure level on pavement surface condition can be best demonstrated for a given traffic loading by considering this effect with pavement age.

After investigating the available data, it was found that the number of contract sections that received only premix leveling or seal coating was very small. These activities were performed along with other activities. Therefore, to include implicitly the effect of these activities on ΔRN, pavement sections that received any of the following combinations of maintenance activities were classified under maintenance category of " All Patching and Sealing (APS) ":

1. Patching and premix leveling or seal coating or both.
2. Patching, joint and crack sealing, and premix leveling or seal coating or both.
3. Joint and crack sealing and premix leveling or seal coating or both.

Table 6.1 shows the distribution of pavement contract sections by routine maintenance category (P, PS, and APS) and by region for each highway class - pavement type combination. As in Chapter 5, contract sections with only one roughness reading or contract sections that did not receive any routine maintenance work during the period of study were excluded from the analysis. As shown in Table 6.1, only two OSH rigid pavement contract sections received APS. This is because pavement distresses to be repaired by premix leveling or seal coating are rarely encountered. The table also confirms that premix leveling or seal coating are not performed on Interstates and they are resurfaced instead.

6.2.2 Statistical Characteristics of Pavement Contract Sections by Highway Class

Pavement contract sections were grouped based on the type of routine maintenance performed. In addition to

Table 6.1 Distribution of Contract Sections by Region and by Routine Maintenance Category for Each Highway Class - Pavement Type Combination.

Region	Routine Maintenance Category	Interstate Highways		Other State Highways (OSH)		
		Rigid	Overlaid	Flexible	Rigid	Overlaid
North	Patching	3	12	37	15	27
	Patching and Jt.& Crack Sealing	15	4	19	15	19
	All Patching and Sealing	-	-	10	-	5
South	Patching	25	9	41	29	20
	Patching and Jt.& Crack Sealing	12	6	25	28	38
	All Patching and Sealing	-	-	11	2	8

routine maintenance expenditure level, other variables, such as pavement age, mean annual ESAL, and Σ ESAL, were included to describe the characteristics of these contract sections. As shown in Tables 6.2 to 6.6, the analysis was conducted by region and for each highway class - pavement type combination. For each of the factors included in the analysis, three statistical parameters were computed: the mean, the standard deviation, and the range.

In general, the average ages of Interstate pavement sections were less than those of OSH sections. For example, as shown in Tables 6.2 and 6.4, while the average age of Interstate rigid pavement sections that received PS in the northern region was about 16 years, the corresponding age of the OSH rigid sections was 25 years. Similarly, for the overlaid pavements, the average ages for the Interstate and OSH in the southern region were about 5 and 9 years, respectively.

To study the effect of routine maintenance expenditure level on the deterioration in pavement surface condition, a useful parameter that should be considered is traffic loading represented by ESAL. It can be observed from Tables 6.2 to 6.5 that there was a difference in the mean annual ESAL between the Interstate and OSH systems. For example, as shown in Tables 6.3 and 6.5, the mean annual ESAL on Interstate rigid pavement sections that received patching

Table 6.2 Statistical Characteristics of Interstate Pavement Contract Sections which Received Patching and Joint and Crack Sealing (PS).

Pavement Type	Variables	Northern Region				Southern Region			
		Mean	Range		Stand. Dev.	Mean	Range		Stand. Dev.
			Min.	Max.			Min.	Max.	
Rigid	Patching and Jt. & Crack Sealing ($/lane-mile/yr)	177	48	405	100	150	42	301	80
	Age (years)	16.3	14	17	1.2	15.3	14	17	0.9
	ESAL ($\times 10^3$)	447	390	557	64	383	206	443	61
	ΣESAL ($\times 10^3$)	7215	6633	8348	660	5868	3288	7086	986
Overlaid	Patching and Jt. & Crack Sealing ($/lane-mile/yr)	279	206	404	88	239	172	358	66
	Age (years)	6.0	5	7	1.2	5.3	3	7	1.9
	ESAL ($\times 10^3$)	181	173	189	9	237	166	273	55
	ΣESAL ($\times 10^3$)	1094	864	1324	266	1346	498	1911	669

Table 6.3 Statistical Characteristics of Interstate Pavement Contract Sections which Received Patching (P).

Pavement Type	Variables	Northern Region				Southern Region			
		Mean	Range		Stand. Dev.	Mean	Range		Stand. Dev.
			Min.	Max.			Min.	Max.	
Rigid	Patching ($/lane-mile/yr)	151	132	160	16	72	8	492	108
	Age (years)	18.3	17	19	1.2	14.2	10	19	1.9
	ESAL ($\times 10^3$)	408	403	410	4	374	135	716	150
	ΣESAL ($\times 10^3$)	6926	6848	6965	68	5241	2265	9302	2052
Overlaid	Patching ($/lane-mile/yr)	76	12	242	73	103	2	203	69
	Age (years)	4.8	2	7	1.85	6.7	2	8	2.0
	ESAL ($\times 10^3$)	178	134	216	31	264	131	469	138
	ΣESAL ($\times 10^3$)	881	268	1513	389	1813	418	3280	1132

Table 6.4 Statistical Characteristics of OSH Pavement Contract Sections which Received Patching and Joint and Crack Sealing (PS).

Pavement Type	Variables	Northern Region				Southern Region			
		Mean	Range		Stand. Dev.	Mean	Range		Stand. Dev.
			Min.	Max.			Min.	Max.	
Flexible	Patching and Jt. &Crack Sealing ($/lane-mile/yr)	344	68	745	225	479	108	1442	320
	Age (years)	8.9	1	27	6.8	11.8	1	34	8.2
	ESAL ($\times 10^3$)	17	3	55	16	15	1	65	15
	ΣESAL ($\times 10^3$)	151	16	759	200	209	9	1951	389
Rigid	Patching and Jt. &Crack Sealing ($/lane-mile/yr)	350	107	769	198	360	53	1048	240
	Age (years)	25	8	32	7.9	16.4	8	28	6.8
	ESAL ($\times 10^3$)	46	31	79	13	64	16	202	55
	ΣESAL ($\times 10^3$)	1111	389	2053	438	1255	165	4045	1349
Overlaid	Patching and Jt. &Crack Sealing ($/lane-mile/yr)	296	97	539	94	240	16	744	142
	Age (years)	8.1	1	16	3.9	9.2	1	31	7
	ESAL ($\times 10^3$)	46	18	110	27	38	7	135	33
	ΣESAL ($\times 10^3$)	369	110	1310	350	353	9	1537	394

Table 6.5 Statistical Characteristics of OSH Pavement Contract Sections which Received Patching (P).

Pavement Type	Variables	Northern Region				Southern Region			
		Mean	Range		Stand.	Mean	Range		Stand.
			Min.	Max.	Dev.		Min.	Max.	Dev.
Flexible	Patching ($/lane-mile/yr)	133	6	515	118	110	4	365	72
	Age (years)	15.8	1	47	11	10.9	3	32	6.9
	ESAL ($\times 10^3$)	21	2	109	23	17	2	61	13
	ΣESAL ($\times 10^3$)	258	20	1365	305	192	13	1412	246
Rigid	Patching ($/lane-mile/yr)	152	4	353	122	240	5	982	236
	Age (years)	19.7	8	26	6.5	20	8	34	8.9
	ESAL ($\times 10^3$)	51	14	90	21	68	12	201	63
	ΣESAL ($\times 10^3$)	1060	142	2053	597	1188	172	4182	1066
Overlaid	Patching ($/lane-mile/yr)	117	5	378	83	86	14	236	54
	Age (years)	11.1	5	34	6.4	11.2	1	26	7.1
	ESAL ($\times 10^3$)	39	8	90	29	26	9	52	21
	ΣESAL ($\times 10^3$)	429	55	1428	321	275	20	970	213

Table 6.6 Statistical Characteristics of OSH Pavement Contract Sections which Received All Patching and Sealing (APS).

Pavement Type	Variables	Northern Region				Southern Region			
		Mean	Range		Stand. Dev.	Mean	Range		Stand. Dev.
			Min.	Max.			Min.	Max.	
Flexible	All Patching and Sealing ($/lane-mile/yr)	1238	225	2258	654	803	140	2685	855
	Age (years)	15	5	29	9.8	8.8	6	21	4.2
	ESAL ($\times 10^3$)	11	2	34	10	18	6	40	12
	ΣESAL ($\times 10^3$)	145	12	448	132	181	46	700	196
Rigid Overlaid	All Patching and Sealing ($/lane-mile/yr)	594	277	812	200	404	10	962	349
	Age (years)	15	7	25	7.4	11.9	2	31	10.7
	ESAL ($\times 10^3$)	19	8	46	17	35	15	141	43
	ΣESAL ($\times 10^3$)	355	57	878	382	593	33	3388	1143

Note: Only two pavement contract sections in the southern region received All Patching and Sealing activities during the study period.

in the northern region was about eight times than that of the OSH system. This difference in ESAL is due to the higher ADT and higher percentage of trucks on Interstate highways (see Table 4.7).

It was also observed that the average expenditure level of routine maintenance on OSH pavements was more than that on Interstate pavements. For example, as shown in Tables 6.2 and 6.4, the average expenditure level of PS on OSH rigid pavement in the southern region was $360/lane-mile/year, the corresponding expenditure level on Interstate rigid pavement was $150/lane-mile/year. This difference may be due to the fact that Interstate highways more often than OSH are resurfaced and thus require less routine maintenance.

6.3 Development of Models for Deterioration in Pavement Surface Condition

6.3.1 Feasibility of Developing Separate Models for Each Pavement Age Group

A relationship between pavement age and routine maintenance expenditure level was introduced in the proposed methodology. As explained in Section 3.4, pavement age was divided into three groups, and it was assumed that the effect of routine maintenance expenditure level on

pavement condition would vary among these age groups (see Figure 3.1). To prove this assumption, actual data on pavement contract sections with different ages are needed.

Logically, the effect of routine maintenance expenditure level on deterioration in pavement surface condition should be investigated separately for each age group. So, the available pavement contract sections were grouped into categories based on a five year increment of pavement age. Tables 6.7 and 6.8 show the number of contract sections in each age category for Interstate and OSH, respectively. These tables also show the distribution of pavement contract sections by region and by routine maintenance category for each pavement type.

It is clear in Table 6.7 that there were no observations in many of the Interstate age categories and in some the number of sections was very small. Also, it can be observed from Table 6.8 that the number of OSH pavement sections that received APS activities was not enough to be analyzed separately for each age group. Furthermore, it was found that the number of pavement sections which can be used to represent Age Group III (old pavement sections) was very small in most cases. This is because pavements in poor condition usually receive resurfacing or other improvement activities instead of routine maintenance.

Table 6.7 Distribution of Interstate Contract Sections by Pavement Age.

Pavement Type	Routine Maintenance Category	Northern Region				Southern Region			
		<5	6-10	11-15	16-20	<5	6-10	11-15	16-20
Rigid	Patching	-	-	-	3	-	2	20	3
	Patching and Joint & Crack Sealing	-	-	4	11	-	-	7	5
Overlaid	Patching	8	4	-	-	1	8	-	-
	Patching and Joint & Crack Sealing	2	2	-	-	2	4	-	-

Table 6.8 Distribution of OSH Contract Sections by Pavement Age.

Pavement Type	Routine Maintenance Category	Northern Region							Southern Region						
		< 5	6 – 10	11 – 15	16 – 20	21 – 25	26 – 30	> 30	< 5	6 – 10	11 – 15	16 – 20	21 – 25	26 – 30	> 30
Flexible	Patching	7	10	6	1	4	6	3	8	18	9	–	4	1	1
	Patching and Jt. & Crack Sealing	7	7	2	1	1	1	–	4	11	4	1	3	1	1
	All Patching and Sealing	1	3	2	–	1	3	–	–	10	–	–	1	–	–
Rigid	Patching	–	3	–	3	6	3	–	–	4	9	3	4	3	6
	Patching and Jt. & Crack Sealing	–	2	–	–	5	2	6	–	9	4	7	5	3	–
	All Patching and Sealing	–	–	–	–	–	–	–	–	–	–	–	1	–	1
Overlaid	Patching	2	17	2	4	1	–	1	3	10	3	1	2	1	–
	Patching and Jt. & Crack Sealing	5	11	2	1	–	–	–	18	8	7	2	–	2	1
	All Patching and Sealing	–	2	1	1	1	–	–	3	2	–	1	1	–	1

It was not feasible to develop separate pavement models for each age group because of small sample sizes. Therefore, it was decided to include pavement age as a quantitative variable in the models. The effect of pavement age on the deterioration in pavement surface condition and consequently on maintenance effectiveness was examined through these models.

6.3.2 Functional Forms of Deterioration in Pavement Surface Condition

As mentioned earlier, it was decided to use change in pavement roughness as a measure of deterioration in pavement surface condition. Change in roughness (ΔRN) is defined as the difference between two successive roughness number readings measured on any given contract section. ΔRN has been used in several studies [19,25] as a very useful indicator to determine the need for maintenance or rehabilitation. In this research, ΔRN was calculated as follows:

$$\Delta RN = RN_{85} - RN_{84} \tag{6.1}$$

where,

ΔRN = change in pavement roughness

RN_{84} = roughness measurement in 1984 (counts/mile)

RN_{85} = roughness measurement in 1985 (counts/mile)

To study the effect of not only routine maintenance expenditure level on pavement surface condition, but also the effect of maintenance type, pavement contract sections were grouped based on routine maintenance category. Pavement sections that received P, PS, or APS were analyzed separately. In order to develop models, the functional forms of these models should be investigated. To decide whether the functional forms are linear or nonlinear, the dependent and independent variables were first determined. ΔRN was used as the dependent variable in these models. Pavement sections with both negative and positive changes in roughness were considered. For the purpose of consistency, the negative values of ΔRN were converted to positive values by adding a constant number (2000) to each of the positive and negative values of ΔRN . Routine maintenance expenditure level, pavement age, mean annual ESAL, and cumulative ESAL were used as independent quantitative variables and region as an independent qualitative variable.

Second, ΔRN values were plotted against each of the independent quantitative variables by routine maintenance category and for each highway class - pavement type combination. The Statistical Analysis System (SAS) computer package [76] was used to conduct this analysis. In most of the cases, it was found that without performing any

transformation, the points were widely scattered. So, the transformation procedure, discussed in Reference 74, was applied in order to obtain the best fit for each case. In general, it was found that P and APS models were improved (the scattering decreased) after applying $\log_{10}$ transformation on the dependent variable. On the other hand, the best functional form of PS models was obtained when $\log_{10}$ transformation was applied on the dependent and independent variables. The reason behind having the same functional form for P and APS models is the fact that major parts of APS maintenance category were found to be patching and premix leveling.

The final functional forms of the models are as given below:

$$\text{Log}_{10}(\Delta RN) = f[P, \text{Age}, ESAL, \Sigma ESAL, R] \tag{6.2}$$

$$\text{Log}_{10}(\Delta RN) = f[APS, \text{Age}, ESAL, \Sigma ESAL, R] \tag{6.3}$$

$$\text{Log}_{10}(\Delta RN) = f[\text{Log}_{10}(PS), \text{Log}_{10}(\text{Age}), \text{Log}_{10}(ESAL), \text{Log}_{10}(\Sigma ESAL), R] \tag{6.4}$$

where,

ΔRN = change in pavement roughness

P = patching expenditure level (\$/lane-mile/year)

APS = all patching and sealing expenditure level (\$/lane-mile/year)

PS = patching and joint and crack sealing expenditure level ($/lane-mile/year)

Age = pavement age since construction or last resurfacing in years

ESAL = mean annual equivalent single axle load in thousands

ΣESAL = total accumulated ESAL in thousands (the product of pavement age and mean annual ESAL)

R = dummy variable: 0 for northern region and 1 for southern region

The interaction term between routine maintenance expenditure level and region was not considered in the development of these functional forms for the following reasons. The interaction term was found not to be significant in most of the regression models developed in Chapter 5. Also, the inclusion of this term would have required the analysis of the effects of all remaining interaction terms resulting in many variables for which very limited data were available.

6.4 Interstate Surface Condition Deterioration Models

A correlation analysis was performed on all the variables discussed in Section 6.3.2. APS maintenance category was not considered in the analysis because none of

the Interstate pavements had received premix leveling or seal coating. The correlation matrices which show the coefficients of correlation for all pairs of dependent and independent variables are given in Tables B.1 and B.2 in Appendix B. The following observations can be made from the correlation matrices: (i) In all cases, routine maintenance expenditure level was found correlated negatively to deterioration in pavement surface condition (ΔRN). In other words, low increase in roughness was associated with high level of maintenance expenditure. (ii) Sections with PS expenditure showed a better correlation with ΔRN than those with P expenditure. (iii) In general, mean annual ESAL correlated better with ΔRN than pavement age or total accumulated ESAL. (iv) Most of the independent variables were found to have low correlation coefficients (less than 0.5).

Based on these findings, it was decided to develop full and reduced models for Interstate surface condition deterioration. The full models included all the independent variables. The reason behind developing full models was to examine the level of significance of each of the included variables. A level of significance of α = .05 was used for full models. The forward stepwise regression search method [74] with α = .15 was used to develop the reduced models. This search method was performed to avoid

the problem of multi-collinearity (high correlation coefficient) which was found especially between ΣESAL and ESAL.

Tables 6.9 and 6.10 show the statistical characteristics of the Interstate surface condition deterioration models for P and PS maintenance categories, respectively. As shown in these tables, most of the reduced models included the same variables (maintenance expenditure level, mean annual ESAL, and region). Although, the effect of pavement age on ΔRN was found highly significant in the full models of PS, the reduced models did not include this factor. This is because, as shown in Tables 6.2 and 6.3, the variation in the ages of Interstate pavements were not high. The reduced models included the mean annual ESAL, because of the nature of the available data this variable was found better correlated with surface condition deterioration than either pavement age or ΣESAL.

It is clear in Tables 6.9 and 6.10 that although two variables, and in some cases more, were eliminated, the R^2 values of the full and reduced models were found to be close. Therefore, it was decided to use the reduced models in order to predict the deterioration in Interstate pavement surface condition. These models are given in Equations 6.5, 6.6, and 6.7 below.

Table 6.9 Statistical Characteristics of Interstate Patching (P) Effect Models.

Criterion	Full Models		Reduced Models	
	Rigid	Overlaid	Rigid*	Overlaid
Number of Observations	28	21	28	21
Coeff. of Determination (R^2)	0.13	0.79	-	0.77
Adjusted Coeff. (adj. R^2)	-0.01	0.74	-	0.75
Linearity Test				
F-Value	0.68	11.30	-	19.37
α Level	0.645	0	-	0
Significance Test for Coefficients				
P				
F-Value	0.02	23.07	-	10.27
α Level	0.903	0	-	0.005
Age				
F-Value	0.03	0.36	-	-
α Level	0.875	0.556	-	-
ESAL				
F-Value	0.29	0.03	-	13.43
α Level	0.594	0.860	-	0.002
Σ ESAL				
F-Value	0.41	0.78	-	-
α Level	0.53	0.391	-	-
Region				
F-Value	2.39	8.88	-	10.86
α Level	0.136	0.009	-	0.004

*No reduced model was feasible.

Table 6.10 Statistical Characteristics of Interstate Patching and Joint and Crack Sealing (PS) Effect Models.

Criterion	Full Models		Reduced Models	
	Rigid	Overlaid	Rigid	Overlaid
Number of Observations	27	10	27	10
Coeff. of Determination (R^2)	0.51	0.98	0.42	0.90
Adjusted Coeff. (adj. R^2)	0.41	0.96	0.39	0.88
Linearity Test				
F-Value	4.32	37.03	8.63	18.42
α Level	0.007	0.002	0.002	0.002
Significance Test for Coefficients				
Log_{10}(PS)				
F-Value	9.92	18.18	7.30	10.00
α Level	0.005	0.013	0.012	0.013
Log_{10}(Age)				
F-Value	3.26	14.30	-	-
α Level	0.085	0.019	-	-
Log_{10}(ESAL)				
F-Value	3.20	14.27	7.95	6.13
α Level	0.088	0.020	0.009	0.048
Log_{10}(ΣESAL)				
F-Value	3.25	14.29	-	-
α Level	0.086	0.019	-	-
Region				
F-Value	0.12	16.48	-	8.72
α Level	0.728	0.015	-	0.021

For Interstate rigid pavements:

$$\text{Log}_{10}(\Delta RN) = 4.05 - 0.06\text{Log}_{10}(PS) - 0.22 \text{ Log}_{10}(ESAL) \tag{6.5}$$

For Interstate overlaid pavements:

$$\text{Log}_{10}(\Delta RN) = 3.8 - 0.14 \text{ Log}_{10}(PS) - 0.1 \text{ Log}_{10}(ESAL) + 0.027 \text{ R} \tag{6.6}$$

$$\text{Log}_{10}(\Delta RN) = 3.28 - 0.0004 \text{ P} + 0.0002 \text{ ESAL} + 0.031 \text{ R} \tag{6.7}$$

The variables in these equations are defined in Section 6.3.2. Only Equation 6.5 did not include the region variable. This variable was found not highly significant in Equation 5.4. This is because, as shown in Table 6.2, Interstate rigid pavement sections that received PS had approximately the same averages and ranges of ESAL and pavement age in both regions.

6.5 Other State Highways (OSH) Surface Condition Deterioration Models

All the variables that were included in the functional forms were considered in the process of developing prediction models for OSH surface condition deterioration. The correlation analysis was conducted separately by

routine maintenance category and for each pavement type. The correlation matrices for these variables are shown in Tables B.3 to B.5 in Appendix B.

An inspection of the correlation matrices revealed that regardless of maintenance category or pavement type, routine maintenance expenditure level was negatively correlated with ΔRN. The same conclusion was derived from the Interstate correlation matrices, but the correlation coefficients were relatively higher for Interstate pavements. As shown in Tables B.3 to B.5, APS expenditure level was found correlated better with ΔRN than P or PS expenditure level for OSH pavements. Also, in three cases, as shown in Tables B.3(a), B.3(b), and B.4(c), pavement age was found correlated better with ΔRN than either mean annual ESAL or ΣESAL.

Based solely upon the values of their respective coefficients of correlation with the dependent variable ΔRN, none of the variables (pavement age, ESAL, or ΣESAL) appeared to be the best candidate for inclusion in the final models. Initially, the stepwise regression search method [74] was used to arrive at a 'best' set of independent variables. In most cases, the reduced models did not include the same variables, and in some cases none of the independent variables could be included. Unlike the Interstate models, the mean annual ESAL variable did not

get included in most of the OSH models. This may possibly due to the fact that the traffic level on OSH is considerably lower than on Interstate highways. The pavement age variable was included in some of the OSH models, while it was not included in all Interstate models. This is possibly because, as explained in Section 6.2.2, the age variation of Interstate pavement sections were, in general, less than those of OSH sections.

In order to facilitate the consideration of the effects of different factors on a unified basis, it was decided finally to include all the variables in OSH models. A high level of confidence with α = .05 was used to test the significance of all prediction models. The formulas and the statistical characteristics of these models are presented by maintenance category and pavement type in the sections below.

6.5.1 All Patching and Sealing (APS) Effect Models

The main purpose of developing APS models was to detect the effect of periodic maintenance activities such as seal coating and premix leveling. Only two OSH rigid pavement sections received some of the the activities included in APS category during the study period. So, models were developed for flexible and overlaid pavements.

For OSH flexible pavements:

$$\mathrm{Log}_{10}(\Delta RN) = 4.08 - 0.0003\ APS - 0.024\ Age - 0.031\ ESAL + 0.0017\ \Sigma ESAL - 0.022\ R \tag{6.8}$$

For OSH overlaid pavements:

$$\mathrm{Log}_{10}(\Delta RN) = 3.52 - 0.0001\ APS - 0.003\ Age - 0.005\ ESAL + 0.0002\ \Sigma ESAL - 0.054\ R \tag{6.9}$$

A summary of the characteristics of these models is given in Table 6.11. It is clear in this table that both models were found significant at $\alpha < .05$. Relatively high R^2 values were obtained, and the difference between these values and the corresponding adjusted R^2 values was found small for both models. This is probably because of the following reasons: (i) Major parts of APS are premix leveling and seal coating, and these activities usually cover wide areas of pavement sections. So, it was easier to identify the specific locations of these activities than those of patching or crack sealing. (ii) The quality of work in premix leveling and seal coating is relatively high, probably because these activities are done by contract in most subdistricts in Indiana and they are closely supervised.

Table 6.11 Statistical Characteristics of OSH All Patching and Sealing (APS) Effect Models.

Criterion	Flexible	Overlaid
Number of Observations	21	13
Coeff. of Determination (R^2)	0.78	0.80
Adjusted Coeff. (adj. R^2)	0.73	0.71
Linearity Test		
F-Value	10.64	5.74
α Level	0	0.02
Significance Test for Coefficients		
APS		
F-Value	18.68	8.73
α Level	0	0.02
Age		
F-Value	10.75	1.95
α Level	0.005	0.205
ESAL		
F-Value	15.27	5.43
α Level	0.001	0.053
ΣESAL		
F-Value	8.75	4.74
α Level	0.01	0.066
Region		
F-Value	5.63	6.12
α Level	0.031	0.043

As shown in Table 6.11, almost all the variables in Equations 6.8 and 6.9 were found highly significant. So, it was assumed that these models could be used to relate maintenance effectiveness to pavement age as well as traffic loading. The application of these models is presented in Section 6.6.

6.5.2 Models for Patching (P) and Patching and Joint and Crack Sealing (PS) Effects

The effects of P and PS on pavement surface condition deterioration were analyzed separately. First, the region was introduced as dummy variable, and six models were developed for three pavement types. The statistical characteristics of P and PS models, using the region as a dummy variable, are given in Tables B.6 and B.7 in Appendix B, respectively. In general, low R^2 values were obtained and some of the developed models were found not significant at a level of $\alpha = .05$.

Two observations can be made regarding the low R^2 values and low significance of some of the models: (i) Other State Highways (OSH) are not mile-posted and it was difficult to match specific locations when routine maintenance has been performed, especially patching, with roughness measurement locations. (ii) Routine maintenance

records in the subdistricts included in this study in the southern region were less organized and the location of maintenance activities on Crew Day Cards was less specific. Therefore, regression models were developed separately for northern and southern regions. The statistical characteristics of these models are found in Tables B.8 and B.9 in Appendix B. As shown in these tables, in general, a higher R^2 was obtained for all models in the northern region.

Most of the patching effect models, as shown in Table B.8, were found not significant. This may be due to the fact that patching is a localized work and usually performed to repair spots or small areas of pavement. In addition, it was found that the major part of patching cost was due to shallow patching. Based on these findings, it was decided that none of the patching effect models could be used to relate maintenance effectiveness to pavement age and traffic loading.

As the PS effect models showed a higher R^2 values than P models, PS models were further investigated. The insignificant PS models in Table B.9 were first excluded. Among the significant PS models, some of the individual variables were found not to be highly significant. However, because R^2 values relatively high, these models can be considered. The following models were finally used in

predicting deterioration in pavement surface condition:

For OSH rigid pavements - North:

$$\begin{aligned}\mathrm{Log}_{10}(\Delta RN) = {} & 3.10 - 0.056\ \mathrm{Log}_{10}(PS) + \\ & 1.78\ \mathrm{Log}_{10}(Age) + 1.6\ \mathrm{Log}_{10}(ESAL) - \\ & 1.53\ \mathrm{Log}_{10}(\Sigma ESAL)\end{aligned} \tag{6.10}$$

For OSH overlaid pavements - North:

$$\begin{aligned}\mathrm{Log}_{10}(\Delta RN) = {} & 3.47 - 0.11\ \mathrm{Log}_{10}(PS) + \\ & 5.84\ \mathrm{Log}_{10}(Age) + 5.43\ \mathrm{Log}_{10}(ESAL) - \\ & 5.38\ \mathrm{Log}_{10}(\Sigma ESAL)\end{aligned} \tag{6.11}$$

For OSH flexible pavements - South:

$$\begin{aligned}\mathrm{Log}_{10}(\Delta RN) = {} & 3.83 - 0.22\ \mathrm{Log}_{10}(PS) + \\ & 1.49\ \mathrm{Log}_{10}(Age) + 1.53\ \mathrm{Log}_{10}(ESAL) - \\ & 1.48\ \mathrm{Log}_{10}(\Sigma ESAL)\end{aligned} \tag{6.12}$$

For OSH overlaid pavements - South:

$$\begin{aligned}\mathrm{Log}_{10}(\Delta RN) = {} & 3.38 - 0.05\ \mathrm{Log}_{10}(PS) - \\ & 0.22\ \mathrm{Log}_{10}(Age) - 0.21\ \mathrm{Log}_{10}(ESAL) + \\ & 0.24\ \mathrm{Log}_{10}(\Sigma ESAL)\end{aligned} \tag{6.13}$$

6.6 Relating Maintenance Effectiveness to Pavement Age and Traffic Loading

One of the important applications of surface condition

deterioration models developed in this research is to relate maintenance effectiveness to pavement age and traffic loading. Various forms for representing maintenance effectiveness have been given in Equations 3.3, 3.4, and 3.5 depending on pavement age group. However, in the context of the present study, maintenance effectiveness can be best represented by the reduction in ΔRN. In the proposed methodology, sections in Age Group II with pavements in good or fair condition were hypothesized to derive most effectiveness from an increased level of maintenance expenditure.

There is no known published information regarding the limits of each age group. However, there is some indications in the literature that were used to delineate the age group limits. Sharaf and Sinha [77] observed that rigid pavements may last for 20 years on the average before being resurfaced, whereas overlaid pavements may need a second resurfacing after 5 to 10 years. Nussbaum and Lokken [78] found that rigid pavements may perform well for 10 years with little maintenance. On the other hand, as stated by Uddin [58], maintenance operations on flexible pavements were found effective at periods between 5 and 15 years.

Based on the findings above, an attempt was made to define Age Groups I and II. Age Group III was not considered because the available data on this age group, as

explained in Section 6.3.1, were insufficient. For the purpose of applying the models, the values of 5 and 15 years were assumed to represent Age Groups I and II, respectively, for flexible pavements. The corresponding values for overlaid pavements were assumed to be 3 and 10 years; respectively. Since rigid pavements usually last for a longer time, 10 and 20 years were used to represent Age Groups I and II, respectively. Although the pavement age variable was not included in the Interstate models because of its relatively narrow distribution, the concept of maintenance effectiveness can be extended to deal with different traffic levels.

6.6.1 Relating Maintenance Effectiveness to Traffic Loading

Equations 6.5, 6.6, and 6.7 were employed to estimate deterioration in Interstate surface condition and consequently maintenance effectiveness for two levels of traffic loading, low and high. ESAL was used as a measure of traffic loading and the ESAL values were computed on the basis of available ADT and truck percentage data for the sections included in the analysis. The ESAL values of 300,000 and 500,000 were used to represent low and high levels on Interstate rigid pavement sections that received PS. The corresponding values for Interstate overlaid pavements receiving PS were 170,000 and 230,000 ESAL,

respectively. The values for Interstate overlaid sections receiving P were 130,000 and 340,000 ESAL, respectively. ΔRN was computed for each traffic loading level under different expenditure levels of routine maintenance.

Figures 6.1 and 6.2 show the effect of PS expenditure level on ΔRN for Interstate rigid and overlaid pavements, respectively. The effect of P expenditure level on ΔRN cannot be represented graphically because of the small differences in the resulting ΔRN values. It is obvious, in Figures 6.1 and 6.2, that as PS expenditure level increases, ΔRN decreases, regardless of traffic level or region. As shown in these figures, the change in pavement roughness was found higher under low traffic level than that under high traffic level. This may be due to the fact that rigid pavements with low traffic level in the data were usually jointed plain or reinforced concrete pavements and joints add to the level of roughness. Also, overlaid pavements with low traffic level may have been designed to have a smaller overlay thickness increasing the possibility of the frequent occurrence of reflection cracks. The data in this research included jointed and continuous reinforced concrete pavements as well as overlaid pavements with different thicknesses.

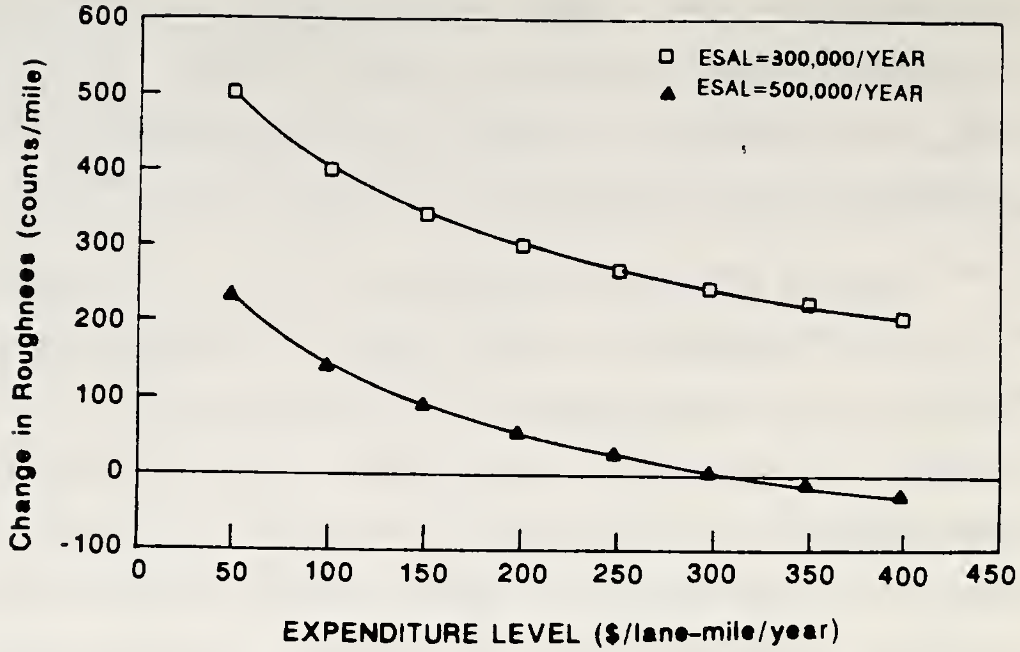


Figure 6.1 Estimated Effect of Patching and Joint and Crack Sealing (PS) Expenditure Level on Change in Roughness for Interstate Rigid Pavement (Equation 6.5).

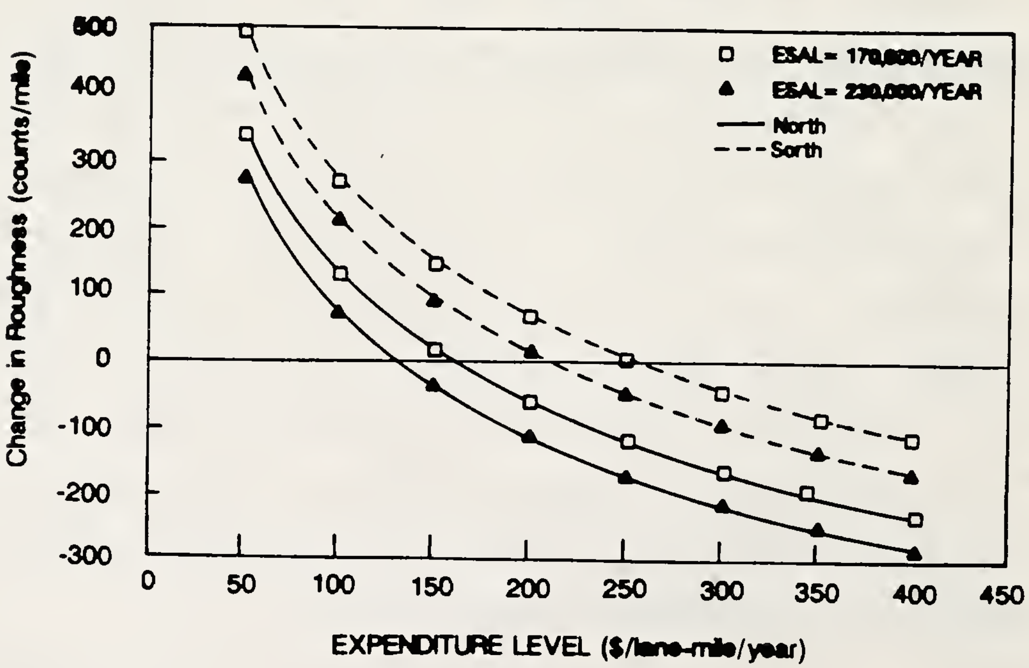


Figure 6.2 Estimated Effect of Patching and Crack Sealing (PS) Expenditure Level on Change in Roughness for Interstate Overlaid Pavement (Equation 6.6).

It is shown in Tables 6.12 and 6.13 that routine maintenance effectiveness for low traffic loading level was higher than that for high level. For example, in Table 6.12, if PS expenditure level increased from \$50 to \$100/lane-mile/year, the reduction in ΔRN for Interstate rigid for low (300,000) and high (500,000) ESAL values were 102 and 91 counts/mile, respectively. From Table 6.13, for Interstate overlaid in the northern region, if PS expenditure level increased by the same amount, the reduction in ΔRN for low (170,000) and high (230,000) ESAL values were 210 and 204 counts/mile, respectively.

Table 6.14 shows the effect of changes in patching expenditure level on reduction in ΔRN for Interstate overlaid pavements. It is clear in this table that patching effectiveness for high traffic loading level was found higher than that for low traffic level. For example, if patching expenditure level increased from \$50 to \$100/lane-mile/year, the reductions in ΔRN for low (130,000) and high (340,000) ESAL values in the southern region were 94 and 103, respectively. A possible reason for this is that thicker overlays are usually constructed on high volume highways and full depth patching is applied using better techniques.

Table 6.12 Estimated Reduction in Change in Pavement Roughness as Patching and Joint and Crack Sealing (PS) Expenditure Level Changes for Interstate Rigid.

Increase in Expenditure Level ($/lane-mile/year) from to	Reduction in Change in Roughness (counts/mile)	
	ESAL = 300,000	ESAL = 500,000
50 - 100	102	91
100 - 150	57	51
150 - 200	40	36
200 - 250	31	27
250 - 300	25	23
300 - 350	20	18
350 - 400	18	16

Table 6.13 Estimated Reduction in Change in Pavement Roughness as Patching and Crack Sealing (PS) Expenditure Level Changes for Interstate Overlaid.

Increase in Expenditure Level ($/lane-mile/year)	Reduction in Change in Roughness (counts/mile)			
	ESAL = 170,000		ESAL = 230,000	
from to	North	South	North	South
50 - 100	210	223	204	217
100 - 150	113	121	111	117
150 - 200	77	82	75	80
200 - 250	58	61	56	60
250 - 300	46	49	44	47
300 - 350	38	40	37	40
350 - 400	32	34	32	33

Table 6.14 Estimated Reduction in Change in Pavement Roughness as Patching (P) Expenditure Level Changes for Interstate Overlaid.

Increase in Expenditure Level ($/lane-mile/year)	Reduction in Change in Roughness (counts/mile)			
	ESAL = 130,000		ESAL = 340,000	
from to	North	South	North	South
50 - 100	87	94	96	103
100 - 150	83	89	91	98
150 - 200	79	85	88	94
200 - 250	76	81	83	90
250 - 300	72	78	80	86

In general, regardless of maintenance category or traffic loading level, it was found that maintenance effectiveness was higher when the increase in expenditure took place at low levels of maintenance expenditure. This result is reasonable because at high levels of expenditure, the need for additional maintenance may become less.

6.6.2 Relating Maintenance Effectiveness to Pavement Age

Equations 6.8 to 6.13 were used to estimate the change in surface roughness of OSH pavements for Age Groups I and II under given traffic loading levels. The levels of traffic loading were estimated from the available data for the sections by pavement type and maintenance category. ΔRN was computed for each value of pavement age and under different expenditure levels of routine maintenance. For the purpose of consistency in the calculations, the interaction term Age*ESAL was used instead of $\Sigma ESAL$ in all OSH models.

In general, regardless of maintenance category, region or pavement type, it was found that ΔRN for Age Group I was higher than that for Age Group II. Thus, maintenance work can be considered to be more effective for Age Group II than that for Age Group I. This conclusion is obvious from the slopes of the curves in Figure 6.3 and the reduction in

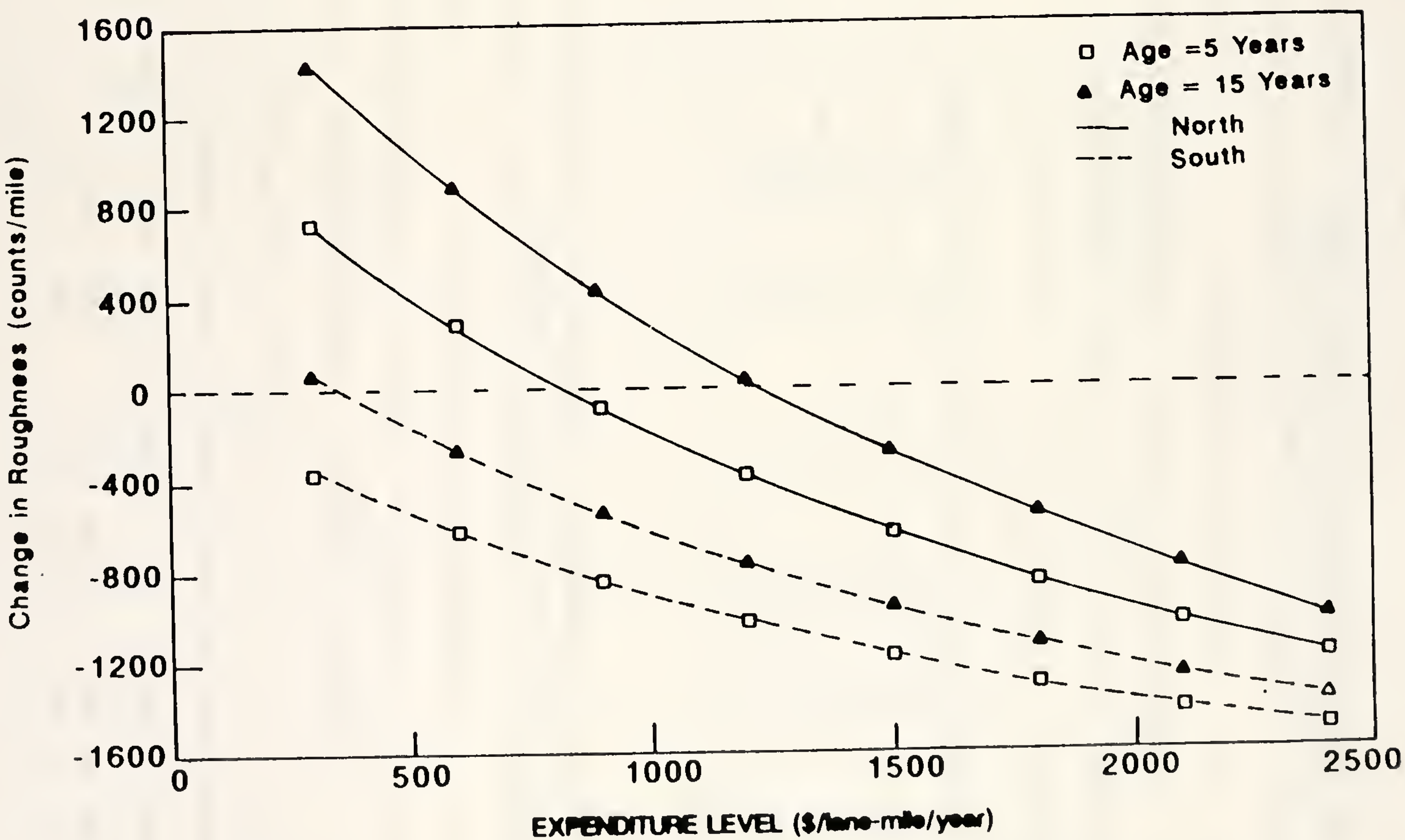


Figure 6.3 Estimated Effect of All Patching and Sealing (APS) Expenditure Level on Change in Roughness for OSH Flexible Pavement (Equation 6.8).

ΔRN in Tables 6.15 and 6.16. For example, as shown in Table 6.15, if APS expenditure level increased from \$300 to \$600/lane-mile/year, the reduction in ΔRN for OSH flexible in the northern region for 5 and 15 years were 432 and 544 counts/mile, respectively. For OSH overlaid in the northern region, and as shown in Table 6.16, if APS expenditure level increased from \$200 to \$400/lane-mile/year, the reductions in ΔRN for 3 and 10 years were 113 and 125 counts/mile, respectively.

Effectiveness of APS maintenance was found noticeable, especially for flexible pavements. This probably reflects the role of seal coating and premix leveling as routine maintenance activities. It may also indicate the importance of performing maintenance operations by contract. The discussion of the results in this section was extended to include a comparison between maintenance effectiveness in the northern and southern regions using the same traffic level. Table 6.17 shows the effect of changes in PS expenditure level on reduction in ΔRN for OSH overlaid in the northern and southern regions. Is is clear in this table that, regardless of pavement age, PS effectiveness was higher in the northern region than in the southern region. This conclusion is also obvious in Figure 6.3 and Tables 6.15 and 6.16.

Table 6.15 Estimated Reduction in Change in Pavement Roughness as All Patching and Sealing (APS) Expenditure Level Changes for OSH Flexible.

Traffic Level = 20,000 ESAL

Increase in Expenditure Level ($/lane-mile/year) from - to	Reduction in Change in Roughness (counts/mile)			
	Age = 5 years		Age = 15 years	
	North	South	North	South
300 - 600	432	260	544	327
600 - 900	364	219	457	276
900 - 1200	305	184	385	232
1200 - 1500	257	155	324	195
1500 - 1800	217	130	273	164
1800 - 2100	182	110	229	138
2100 - 2400	153	92	239	116

Table 6.16 Estimated Reduction in Change in Pavement Roughness as All Patching and Sealing (APS) Expenditure Level Changes for OSH Overlaid.

Traffic Level = 20,000 ESAL

Increase in Expenditure Level $/lane-mile/year from - to	Reduction in Change in Roughness (counts/mile)			
	Age = 3 years		Age = 10 years	
	North	South	North	South
200 - 400	113	101	125	102
400 - 600	108	96	111	98
600 - 800	104	92	105	93
800 - 1000	99	87	101	89

Table 6.17 Estimated Reduction in Change in Pavement Roughness as Patching and Crack Sealing (PS) Expenditure Level Changes for OSH Overlaid.

Traffic Level = 30,000 ESAL

Increase in Expenditure Level ($/lane-mile/year) from to	Reduction in Change in Roughness (counts/mile)			
	Age = 3 years		Age = 10 years	
	North	South	North	South
100 - 200	174	71	196	73
200 - 300	95	41	107	42
300 - 400	65	28	74	29
400 - 500	50	22	55	22
500 - 600	39	17	44	18
600 - 700	32	15	37	16

OSH models can also be used to estimate the change in pavement roughness for different traffic levels. Tables 6.18 and 6.19 show the effect of PS expenditure level on change in roughness for OSH flexible and rigid pavements, respectively. As shown in these tables, the change in pavement surface condition was found higher for high traffic loading levels than that for low traffic loading levels. For example, in Table 6.18 for OSH flexible pavements in Age Group I, the ΔRN values for low (10,000) and high (40,000) ESAL values were 457 and 651 counts/mile, respectively for expenditure level of $200/lane-mile/year. It can also be seen in Table 6.18 that, if PS expenditure level increased from $200 to $400/lane-mile/year, the reductions in ΔRN, for the same pavement age group, were 345 and 372 counts/mile, for ESAL values of 10,000 and 40,000, respectively. These results can possibly be explained by the fact that unlike Interstate pavements, OSH pavements receive routine maintenance for a longer period of time before receiving resurfacing.

6.7 Uses of Pavement Surface Condition Deterioration Models

The models discussed in this chapter may be of use in the following areas:

1. Highway Programming - Any highway program is usually

Table 6.18 Estimated Effect of Patching and Crack Sealing (PS) Expenditure Level on Change in Pavement Roughness for OSH Flexible - Southern Region.

Expenditure Level ($/lane-mile/yr)	Change in Roughness (Counts/mile)			
	ESAL = 10,000		ESAL = 40,000	
	Age=5yr	Age=15yr	Age=5yr	Age=15yr
200	457	485	651	682
400	112	137	279	305
600	-66	-44	86	110
800	-184	-163	-41	-18
1000	-270	-250	-134	-112
1200	-338	-318	-206	-186
1400	-393	-374	-266	-246

Table 6.19 Estimated Effect of Patching and Joint and Crack Sealing (PS) Expenditure Level on Change in Pavement Roughness for OSH Rigid - Northern Region.

Expenditure Level ($/lane-mile/yr)	Change in Roughness (Counts/mile)			
	ESAL = 35,000		ESAL = 65,000	
	Age=10 yr	Age=20 yr	Age=10 yr	Age=20 yr
100	270	710	377	838
200	184	607	286	730
300	134	549	235	669
400	100	508	199	626
500	74	477	172	593
600	53	452	150	567
700	36	430	132	545
800	20	412	116	526

based upon information collected from condition surveys which reflect the performance of pavements and the location of deficient sections. The information concerning pavement roughness, maintenance expenditure, pavement age and traffic loading can be used by program developers at the central office in the process of pavement management. Prediction of pavement condition for pavement sections with different ages and traffic levels can be an useful aid for quick evaluation of network performance at different levels of maintenance funding.

2. Routine Maintenance Planning - The models can be used to obtain information concerning effectiveness of different maintenance types. Such information can be applied by pavement maintenance managers to spend optimally their limited amount of maintenance dollars. In other words, these models may be used to decide how much maintenance to be carried out at each location to achieve the best overall results at network level.

6.8 Chapter Summary

The results of the analyses performed in this chapter indicated that the relationship between routine maintenance and pavement age could not be established well because of

the limited data on pavements, especially for Age Group III when pavements usually are in poor condition. However, change in roughness as a measure of deterioration in pavement surface condition was found a useful evaluation tool for relating maintenance effectiveness to pavement age and traffic loading.

An analysis was first conducted to investigate the functional forms of pavement condition models. In general, the relationship between routine maintenance expenditure level and change in pavement condition was found nonlinear. However, the shapes of these functional forms were found dependent on maintenance category. Models were thus developed by routine maintenance category and for each highway class - pavement type combination.

In most of OSH models, both pavement age and traffic loading variables were found significant. In Interstate models traffic loading (ESAL) was found more significant than pavement age because of the relatively narrow age distribution. So, the effect of pavement age on Interstate pavement surface condition was not considered in the analysis. On the other hand, OSH models were employed to evaluate the effects of pavement age and traffic loading on pavement surface condition deterioration and consequently on maintenance effectiveness.

In general, maintenance effectiveness for Age Group II (pavements are in fair or good condition) was found higher than that for Age Group I (pavements are in very good condition). For OSH pavements, maintenance effectiveness for relatively high traffic loading level was found higher than that for low level. However, for most of Interstate cases, maintenance effectiveness for low traffic loading level was found higher than that for high traffic level. This is probably because Interstate pavements with high traffic level usually receive more frequent resurfacing or other improvement activities.

The effectiveness of maintenance category was also examined. For example, the maintenance work involving premix leveling and seal coating was found to provide relatively a higher effectiveness than the work involving patching and joint and crack sealing. This conclusion reflects to some extent the role of periodic maintenance.

The findings in this chapter agree with those found in Chapter 5 where rate of change in roughness was used as a measure of deterioration in pavement surface condition, and only the effects of maintenance expenditure level and region were considered. Including pavement age and traffic loading in the analysis in this chapter increased R^2 values of the models and added another dimension to the concept of maintenance effectiveness. It should be noted, however,

that because of data limitations of this study, the results cannot be generalized or considered conclusive. The results are relevant only within the data range of the sections included in the study.

CHAPTER 7

EFFECTS OF ROUTINE MAINTENANCE EXPENDITURE LEVEL ON PAVEMENT SERVICE LIFE

7.1 Introduction

In the proposed methodology, presented in Chapter 3, the effect of routine maintenance expenditure level on pavement service life was conceptually introduced based upon the following general assumptions:

a. Pavement roughness was considered a measure of pavement performance instead of PSI.

b. Pavement age at terminal roughness value was assumed to represent pavement service life.

c. Pavement type and highway class were proposed to represent initial design and methods of construction.

The data base, developed in Chapter 4, was used in this chapter to examine the validity or reasonableness of the above assumptions. This chapter also presents a procedure to investigate the effect of routine maintenance

expenditure level on time of resurfacing.

7.2 Identification of Traffic and Maintenance Expenditure Levels

One of the main objectives in this research was to study the effects of routine maintenance expenditure level on pavement service life. Based on that, a relationship between pavement roughness and pavement age as a measure of pavement service life was introduced in the proposed methodology. This relationship was considered valid for small variations in traffic loading. Therefore, it was decided to divide both traffic and maintenance expenditure into two levels, low and high. The purpose of this step was to examine the relationship between pavement roughness and age separately for each traffic-maintenance level combination. The procedures used to determine the cut-off value between the low and high levels are discussed in the sections below.

7.2.1 Determination of Low and High Traffic Levels

Mean Annual ESAL was used as a measure of traffic loading. Two methods were used to determine the cut-off value between the low and high traffic loading levels for each highway class-pavement type combination. These

methods are explained in the sections below.

7.2.1.1 Method 1 - Average ESAL

In order to represent both regions in Indiana using relatively enough sample sizes, the cut-off value between the low and high traffic levels for each highway class-pavement type combination was computed as follows:

Cut-off value = (Avg. ESAL in North + Avg. ESAL in South)/2

7.2.1.2 Method 2 - Use of Fuzzy Sets

The second method was used to verify the results of the first method. Here the theory of fuzzy sets was employed. The terms, such as high or low, are associated with vagueness or fuzziness, and the knowledge and judgment of experienced transportation engineers can be used, in conjunction with fuzzy sets approach, to define the high and low values of traffic. The fuzzy sets approach provides a systematic procedure to handle classes of information in which the transition from membership to nonmembership is gradual rather than abrupt [79]. It can be considered as a modeling language well suited for situations in which fuzzy relations, criteria, and phenomena exist. The fuzzy sets approach was used in

pavement management to develop a fuzzy pavement serviceability rating [80].

A questionnaire was developed and distributed among transportation engineering faculty and staff in the School of Civil Engineering at Purdue University. The questionnaire was to determine the cut-off value between the low and high traffic levels (ESAL) using the fuzzy sets approach.

The questionnaire consisted of four questions repeated for each highway class-pavement type combination. The maximum and minimum values of ESAL data estimated in this research for each combination was also provided. Fifteen returned responses were used to develop membership functions for low and high traffic loading levels. Figures 7.1 to 7.5 show the resulting membership functions. In these figures, the intersection point was considered the cut-off value between the low and high traffic levels.

The cut-off values using Methods 1 and 2 for each highway class-pavement type combination are listed in Table 7.1. As shown in this table, the results of the two methods were found approximately the same. Thus, the cut-off values between the low and high traffic levels obtained using Method 1 were subsequently used in the analysis in this chapter.

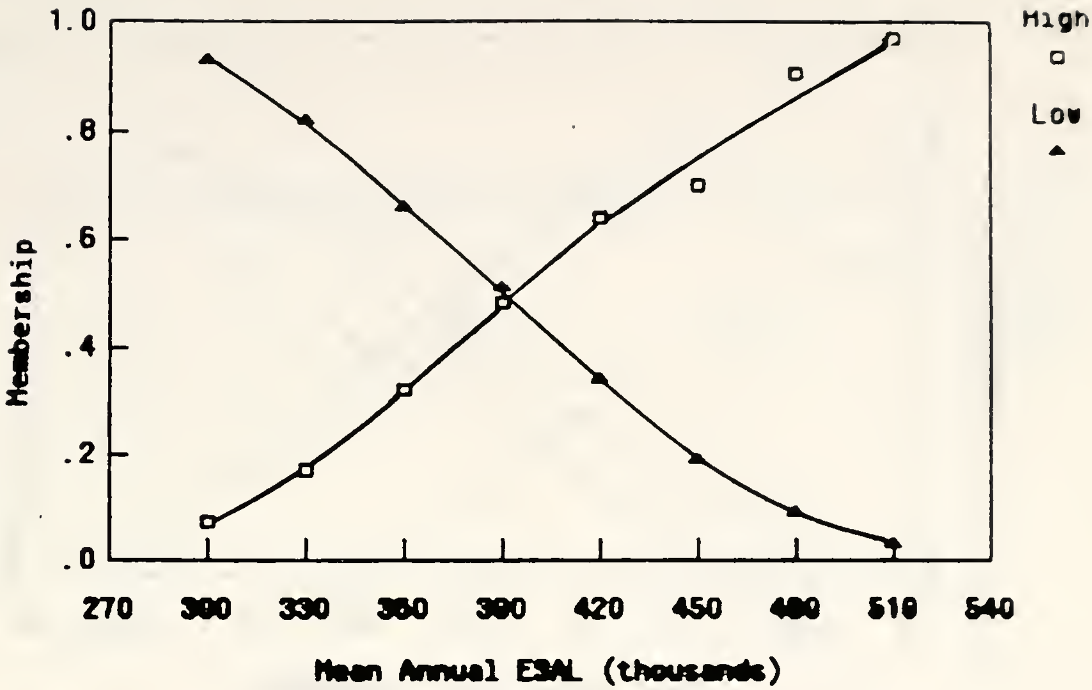


Figure 7.1 Membership Functions for Low and High Traffic Levels for Interstate Rigid Pavement.

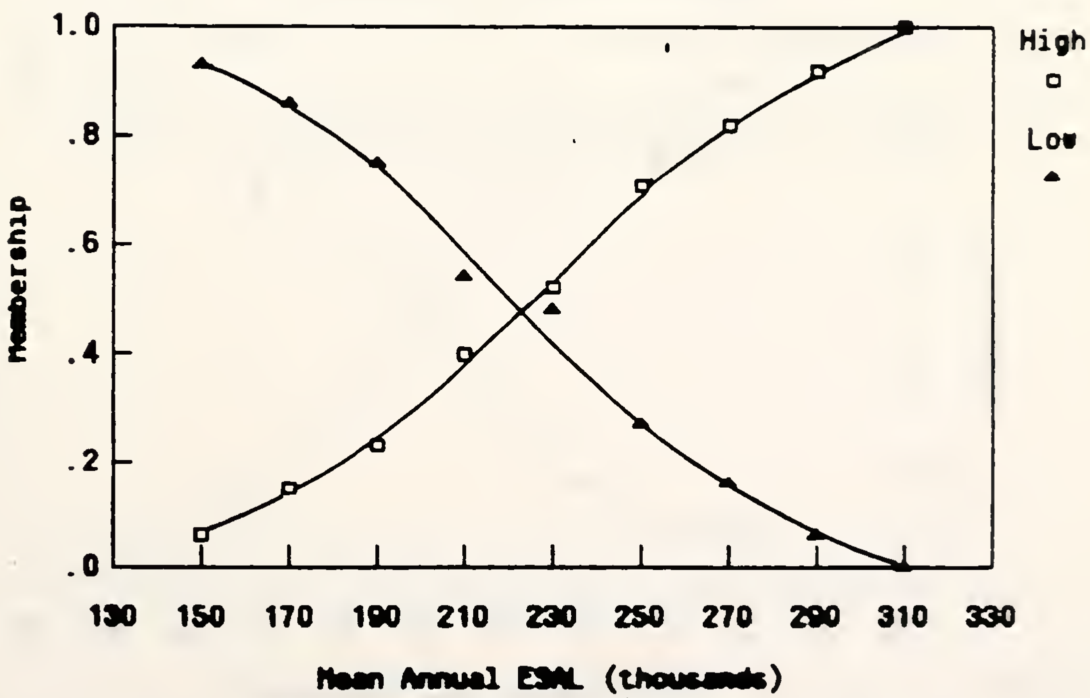


Figure 7.2 Membership Functions for Low and High Traffic Levels for Interstate Overlaid Pavement.

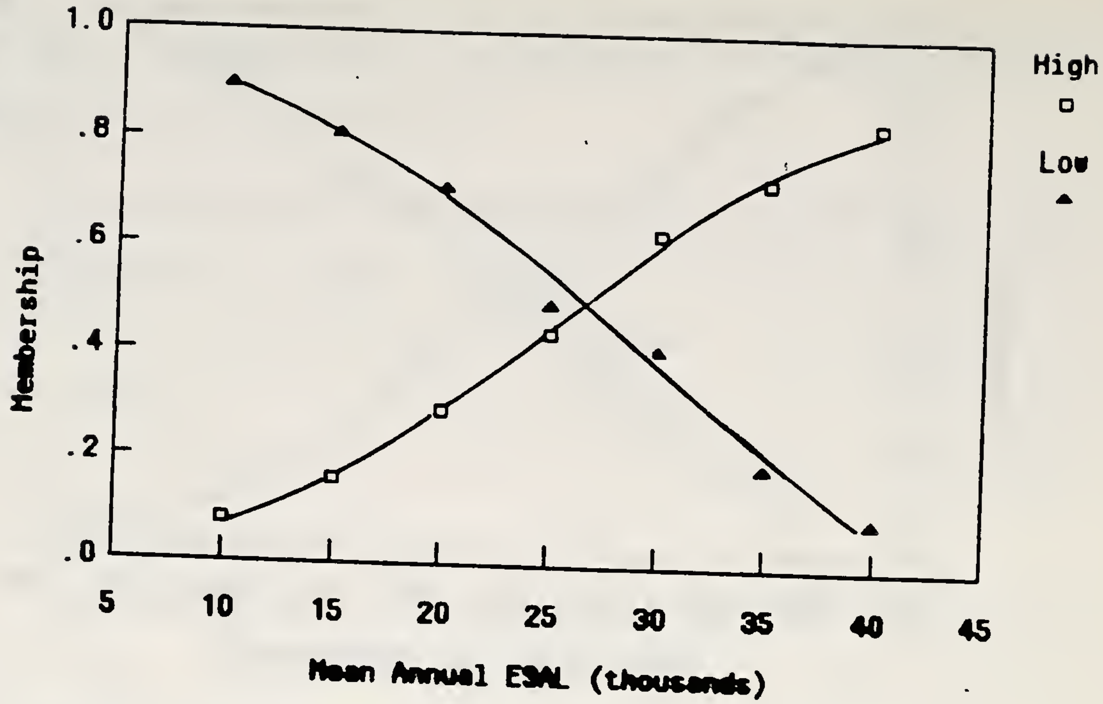


Figure 7.3 Membership Functions for Low and High Traffic Levels for OSH Flexible Pavement.

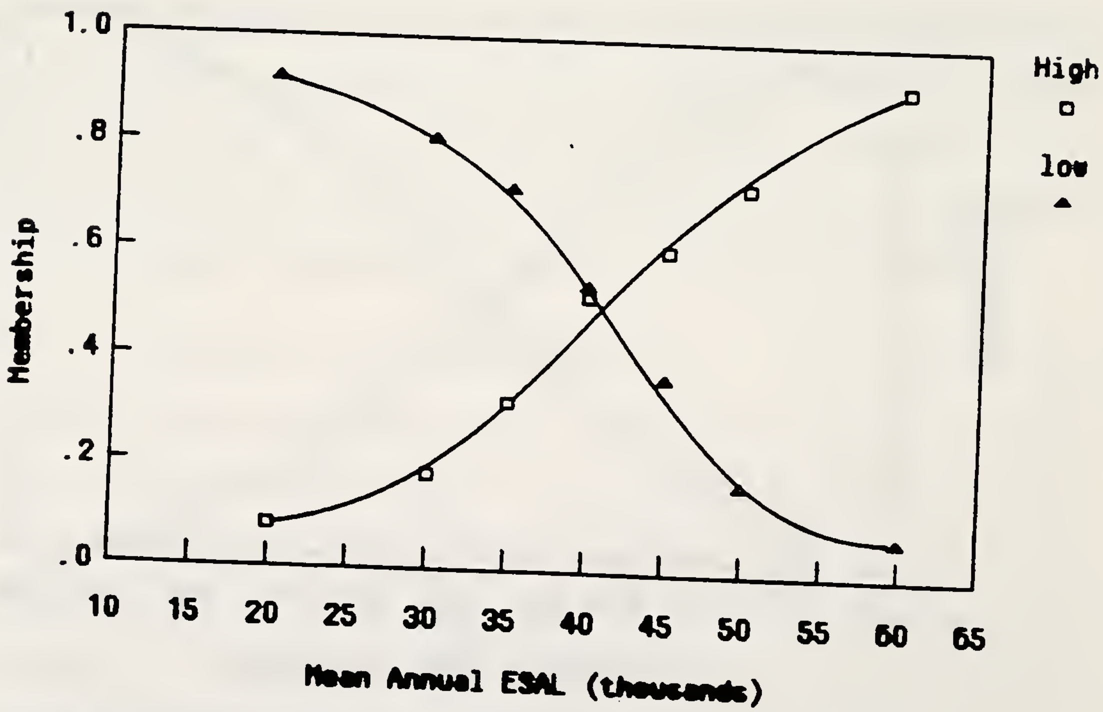


Figure 7.4 Membership Functions for Low and High Traffic Levels for OSH Overlaid Pavement.

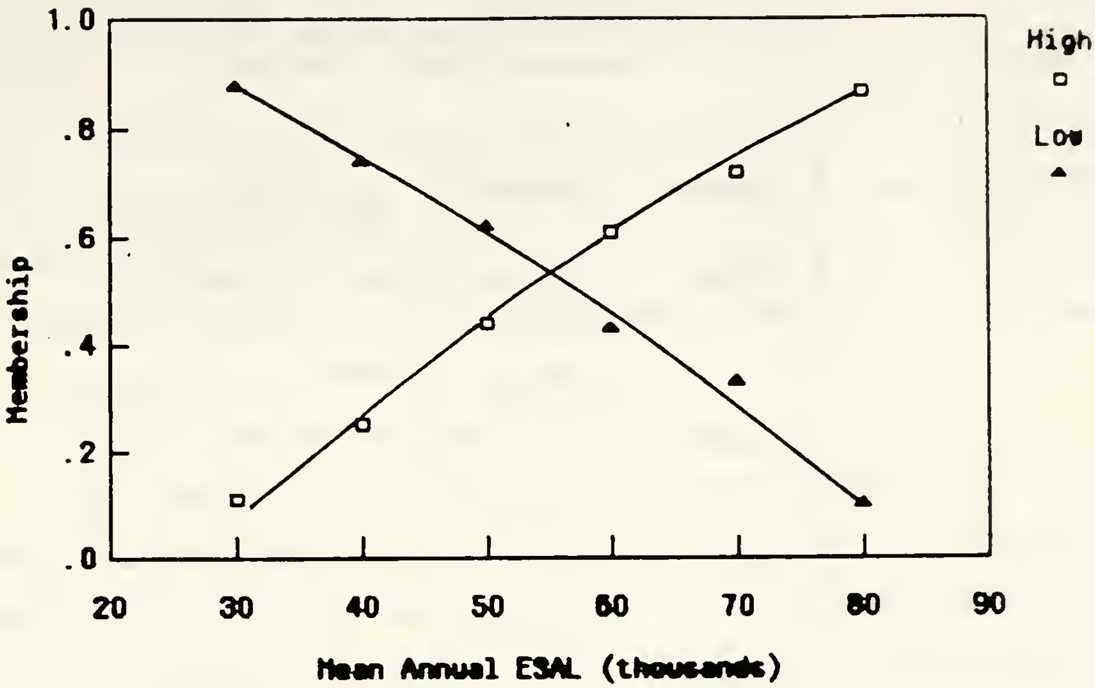


Figure 7.5 Membership Functions for Low and high Traffic Levels for OSH Rigid Pavement.

Table 7.1 Cut-Off Values Between Low and High Levels of Traffic Loading.

Highway Class	Pavement Type	Traffic ESAL (thousands) Method 1	Method 2
Interstate	Rigid	400	395
	Overlaid	215	220
Other State Highways	Flexible	20	26
	Rigid	55	55
	Overlaid	35	40

7.2.2 Determination of Low and High Maintenance Expenditure Levels

Only P and PS maintenance categories were considered in the analysis in this chapter. APS maintenance category was excluded because it was a mix of periodic and annual maintenance activities. Furthermore, to study the effect of premix leveling or seal coating expenditure level on pavement service life, historical data over several years are needed.

The available routine maintenance data for the sections in the study were used to determine low and high expenditure levels. Method 1 was used to determine the cut-off value between the low and high maintenance expenditure level. Method 2 was not used because the results of this method were found close to those of Method 1 in determining the traffic loading levels. The cut-off values between low and high expenditure levels for each maintenance category and for each highway class-pavement type combination are listed in Table 7.2.

7.3 Effect of Pavement Type on the Relationship Between Pavement Roughness and Pavement Age

The relationship between pavement roughness and age, as explained schematically in Figure 3.10, was assumed to

Table 7.2 Cut-Off Values Between Low and High Levels of Maintenance Expenditure.

Highway Class	Pavement Type	Maintenance Expenditure ($/lane-mile/year) Method 1	
		Patching and Jt. & Crack Sealing	Patching
Interstate	Rigid	165	80
	Overlaid	255	90
Other State Highways	Flexible	412	122
	Rigid	355	196
	Overlaid	268	102

be nonlinear. Since the definition of pavement roughness varies depending on the measuring system being response-type or pavement profile, this assumption should be tested. Furthermore, the assumption used in this research was derived from results of earlier studies [41,42], which considered only flexible pavements. The effects of traffic and maintenance expenditure levels on the shape of this relationship were not also considered in earlier studies.

To determine whether the relationship between pavement roughness and age is linear or nonlinear, it was decided to analyze the available data separately by maintenance category, by climatic region, and by highway class-pavement type combination. To take into consideration the effects of traffic and maintenance expenditure levels, the data were further subdivided based upon the following traffic-maintenance level combinations:

a) LL - low maintenance expenditure, low traffic.

b) LH - low maintenance expenditure, high traffic.

c) HL - high maintenance expenditure, low traffic.

d) HH - high maintenance expenditure, high traffic.

Table 7.3 shows the distribution of pavement contract sections for each traffic-maintenance level combination. It is clear in this table that, in some cells, no observations were available especially for Interstate highways. Also,

Table 7.3 Distribution of Pavement Contract Sections for Traffic-Maintenance Levels Combinations.

Highway Class	Pavement Type	Level Combination	Northern Region		Southern Region	
			Patching and Jt. & Crack Sealing	Patching	Patching and Jt. & Crack Sealing	Patching
Interstate	Rigid	LL	3	–	4	10
		LH	3	–	3	9
		HL	4	–	3	2
		HH	5	3	2	4
	Overlaid	LL	2	9	–	3
		LH	–	–	4	–
		HL	–	1	2	2
		HH	2	2	–	4
Other State Highways	Flexible	LL	8	15	11	18
		LH	5	5	1	11
		HL	5	13	7	8
		HH	1	4	6	4
	Rigid	LL	8	6	12	10
		LH	1	2	6	5
		HL	5	3	6	9
		HH	1	4	4	5
	Overlaid	LL	2	7	14	10
		LH	4	2	12	2
		HL	7	7	8	7
		HH	6	11	4	1

the number of contract sections was found very few (less than three observations) in many cases. Therefore, these cases were not considered in the analysis. Regression analysis was performed for each of the remaining traffic-maintenance level combinations. Pavement roughness was used as the dependent variable and pavement age as the independent variable.

The general goodness-of-fit represented by the coefficient of multiple determination (R^2) was mainly used in selecting the best model. For each case, linear and nonlinear models were developed and the R^2 values of these models were compared. The R^2 values of the linear and nonlinear models are given in Tables B.10 and B.11 in Appendix B, respectively. The relationship between pavement roughness and age was found more related to pavement type than to region, highway class, maintenance category, or traffic-maintenance level combination. So, the following general regression models were adopted.

For flexible and rigid pavements:

$$RN = a + b(Age) \tag{7.1}$$

For overlaid pavements:

$$\text{Log}_{10}(RN) = c + d(Age) \tag{7.2}$$

where,

RN = roughness measurement in 1985 in counts/mile.

Age = pavement age since construction or resurfacing, in years.

a,b,c,d = regression parameters.

From Equations 7.1 and 7.2, it can be stated that the relationship between pavement roughness and age was found linear for flexible and rigid pavements and nonlinear for overlaid pavements.

7.4 Suitability of Using Zero-Maintenance Data in Predicting Pavement Service Life

Theoretically, as shown in Figure 3.10, the true total pavement damage may be represented by the area between zero-maintenance curve and no-change line. However, in reality the actual pavement performance curve may lie anywhere between these lines. A study of the effect of zero-maintenance on pavement service life might be useful in and analysis of pavement cycle-life costing. Also, considering the effect of zero-maintenance would help in planning and comparing different maintenance strategies.

For the purpose of investigating the possibility of developing zero-maintenance curves, pavement contract

sections that did not receive any maintenance work during the study period were considered. It was found that a total of 54 contract sections did not receive any routine maintenance during the year of study; twenty-seven contract sections in Interstate and the rest in OSH. Although the total number of OSH contract sections in the data base was about three times the number of Interstate sections, the number of Interstate sections that did not receive routine maintenance was found equal to that of OSH. This is because OSH pavement sections receive routine maintenance for a longer period before being resurfaced that Interstate sections.

The contract sections that did not receive routine maintenance were divided by region, pavement type and traffic loading level (low and high). The distribution of these sections is presented in Table 7.4. As shown in this table, the number of contract sections in the southern region was less than that in the northern region. A possible reason may be the fact that the climatic effect in the northern region is higher, and consequently the need for performing routine maintenance work may be more. Furthermore, the distribution of the contract sections was not uniform and in many cells no observations were available, especially for high traffic level. It was also noticed that most of the contract sections that did not

Table 7.4 Distribution of Contract Sections which Received Zero-Maintenance during the Study Period.

Highway Class	Pavement Type	Traffic Level	Northern Region	Southern Region
Interstate	Rigid	Low	-	12
		High	-	4
	Rigid Overlaid	Low	2	2
		High	-	7
Other State Highways	Flexible	Low	4	7
		High	3	1
	Rigid	Low	1	4
		High	-	-
	Rigid Overlaid	Low	2	5
		High	-	-

receive routine maintenance were newly constructed or resurfaced.

A preliminary analysis indicated that the available information regarding zero-maintenance was not enough to be used in predicting the effect of do-nothing on pavement service life. So, it was decided to exclude the contract sections that did not receive routine maintenance from further analysis.

7.5 Prediction Models for the Effects of Routine Maintenance Expenditure Level on Pavement Service Life

Service life has been defined as the total number of equivalent axle loads or the total number of years that the pavement surface lasts, i.e., traffic load or time between resurfacing [81]. In this research, pavement age at terminal roughness value was assumed to represent pavement service life but for small variation in traffic loading and climatic conditions. The analysis in Section 7.3 was conducted to test whether the relationship between pavement roughness and age is linear or nonlinear. It did not test the level of significance of pavement age and other factors.

To decide which represents pavement service life better, pavement age or total accumulated ESAL at the time

of resurfacing, two general prediction models were developed. In addition to maintenance expenditure level and climatic region, pavement age and ESAL were considered in the first model, while total accumulated ESAL was considered in the second model. Pavement roughness was used as the dependent variable in these models. Furthermore, the models were developed by routine maintenance category and for each highway-pavement type combination. The reason behind including ESAL in the first model was to test the variations in annual traffic loading.

A comparison was made between the two models based upon two criteria: (i) the coefficient of multiple determination (R^2) and (ii) the level of significance of pavement age and and ΣESAL. In general, a much higher R^2 was obtained for the first than the second model. In all cases, except for Interstate rigid pavements, pavement age was found more significant than ΣESAL. In many cases, especially for OSH, ΣESAL was found not significant at a level of $\alpha = 0.10$. Based on these findings, pavement age can be considered more suitable than ΣESAL to represent pavement service life in this research. This conclusion was confirmed by the observation made by Gerhard [82].

To be consistent with what was found in Section 7.3, linear prediction models were developed for flexible and rigid pavements and nonlinear models for overlaid

pavements. In order to obtain the best models, the following steps were taken:

1. The insignificant models were first excluded. A high level of significance with $\alpha = 0.05$ was used to test the significance of all regression models.

2. For OSH, separate models were developed for each region. This is because R^2 values of OSH models were found not high when considering region as a dummy variable. In Interstate models, region was kept as a dummy variable, because of limited number of observations and limited amount of routine maintenance work on Interstate pavements regardless of region.

3. If a model was found significant, but the variable of expenditure level was insignificant at $\alpha = 0.10$, the model was eliminated.

4. In all models the effect of patching was not significant. In some cases, patching expenditure level was found positively correlated with pavement roughness. This mainly occurred in rigid pavements models.

5. The remaining significant models in which ESAL was found insignificant at $\alpha = 0.10$ were re-examined after excluding this variable.

Based on these steps, the following regression models were adopted.

For Interstate overlaid pavements:

$$\mathrm{Log}_{10}(\mathrm{RN}) = 2.9 - 0.002\ \mathrm{PS} + 0.19\ \mathrm{Age} - 0.004\ \mathrm{ESAL} + 0.124\ \mathrm{R} \qquad (7.3)$$

For OSH flexible pavements - North:

$$\mathrm{RN} = 1551 - 1.23\ \mathrm{PS} + 57.1\ \mathrm{Age} - 15\ \mathrm{ESAL} \qquad (7.4)$$

For OSH overlaid pavements - North:

$$\mathrm{Log}_{10}(\mathrm{RN}) = 2.81 - 0.0005\ \mathrm{PS} + 0.047\ \mathrm{Age} \qquad (7.5)$$

where,

RN = roughness measurement in 1985 (counts/mile).

PS = patching and joint and crack sealing expenditure level ($/lane-mile/year).

Age = pavement age since construction or resurfacing, in years.

ESAL = mean annual equivalent single axle load (thousands).

R = dummy variable to represent climatic region: 0 for northern region and 1 for southern region.

A summary of the regression characteristics of the models presented in Equations 7.3 to 7.5 is given in Table 7.5. The models in which ESAL was found significant, Models 7.3 and 7.4, were further investigated. After omitting ESAL variable from both models, it was found that while R^2 of Interstate overlaid model decreased from 0.95 to 0.91, the R^2 of OSH flexible model decreased from 0.53 to 0.42. It is obvious that the decrease in R^2 of Interstate overlaid model is much less than that of OSH flexible model. This is because, as shown in Table 7.5, ESAL in Model 7.4 was found more significant than in Model 7.3.

Based on these findings, separate models were developed for low and high traffic loading levels for OSH flexible in the northern region. In addition, it was decided to exclude ESAL from Interstate overlaid model. This was because of the limited number of observations and eliminating ESAL did not significantly affect R^2. The resulting models are given in Equations 7.6 to 7.8.

For Interstate overlaid pavements:

$$\text{Log}_{10}(\text{RN}) = 2.5 - 0.001\ \text{PS} + 0.09\ \text{Age} - 0.156\ \text{R} \quad (7.6)$$

For OSH flexible pavements - low traffic level - North:

Table 7.5 Statistical Characteristics of Pavement Service Life Prediction Models (Models 7.3 - 7.5).

Criterion	Model (7.3)	Model (7.4)	Model (7.5)
Number of Observations	10	19	19
Coeff. of Determination (R^2)	0.95	0.53	0.77
Adjusted Coeff. (adj. R^2)	0.93	0.47	0.76
Linearity Test			
F Value	24.32	5.67	26.95
α Level	0.002	0.008	0
Significance Test for Coefficients			
PS			
F Value	15.15	5.18	2.89
α Level	0.012	0.040	0.100
Age			
F Value	14.81	10.98	48.55
α Level	0.012	0.005	0
ESAL			
F Value	4.46	3.71	-
α Level	0.090	0.070	-
Region			
F Value	0.80	-	-
α Level	0.410	-	-

$$RN = 1521 - 1.24\ PS + 48\ Age \tag{7.7}$$

For OSH flexible pavements - high traffic level - North:

$$RN = 497 - 0.45\ PS + 85\ Age \tag{7.8}$$

The statistical characteristics of the models presented in Equations 7.6 to 7.8 are given in Table 7.6. Models 7.5 to 7.8 were finally employed in Section 7.6 to relate the time of resurfacing to routine maintenance expenditure level.

7.6 Application of Pavement Service Life Prediction Models

Knowledge of the effects of routine maintenance on pavement service life is important to the management of highway pavements at both network and project levels. One of the important applications of the prediction models developed in this chapter was to estimate the time of resurfacing under different routine maintenance expenditure levels. As stated in the proposed methodology in Chapter 3, pavements need resurfacing when surface roughness reaches the terminal value (RN_T). The terminal roughness can be defined as the roughness level at which a pavement

Table 7.6 Statistical Characteristics of Pavement Service Life Prediction Models (Models 7.6 - 7.8).

Criterion	Model (7.6)	Model (7.7)	Model (7.8)
Number of Observations	10	13	6
Coeff. of Determination (R^2)	0.91	0.41	0.75
Adjusted Coeff. (adj. R^2)	0.88	0.36	0.68
Linearity Test			
F Value	19.63	3.49	4.39
α Level	0.002	0.07	0.13
Significance Test for Coefficients			
PS			
F Value	8.31	3.34	0.29
α Level	0.028	0.098	0.63
Age			
F Value	29.39	4.77	8.48
α Level	0.002	0.054	0.06
Region			
F Value	8.85	-	-
α Level	0.025	-	-

section's serviceability is too low and, hence, it is in need of improvement. From the public's point of view, pavement roughness is more critical than structural adequacy in determining the timing for pavement improvement [83].

The general practice supported by earlier studies [84,85] indicate that PSI values of 2.0 for secondary roads and 2.5 for Interstate and primary highways can be considered as minimum values of acceptable pavement serviceability. In this research, a terminal serviceability index of 2.5 was used for Interstate pavements and 2.2 for OSH pavements.

Three successive studies were conducted by Purdue University and IDOH [86,14,87] in an effort to establish a comprehensive model of statistical correlation between Roadmeter roughness numbers and PSI for the state highway system of Indiana. The results of this research effort are given in Equations 7.9 and 7.10.

For flexible and overlaid pavements:

$$PSI = 8.72 - 1.96633*\text{Log}_{10}(RN) \qquad (7.9)$$

$$r^2 = 0.71$$

For rigid pavement:

$$PSI = 11.73 - 2.83369*\text{Log}_{10}(RN) \qquad (7.10)$$

$$r^2 = 0.68$$

where,

RN = roadmeter counts per mile

r^2 = coefficient of simple determination

The suggested terminal serviceability indices were used in Equations 7.9 and 7.10 to determine the terminal roughness values. The resulting values were 1460, 2070, 1808, and 2307 counts/mile for Interstate overlaid, OSH flexible and overlaid, Interstate rigid, and OSH rigid pavements, respectively. Since no prediction models were developed for rigid pavements, only the first two terminal values were used in determining the time of resurfacing or pavement improvement.

The prediction models in Equations 7.5 to 7.8 were used to compute pavement roughness under low and high PS expenditure levels and for different pavement ages. Based on the findings in Section 7.2.2, \$200 and \$300/lane-mile/year were selected to represent low and high expenditure levels for Interstate overlaid pavements, respectively. Because routine maintenance expenditure level on OSH was found higher than that on Interstate pavements, \$300 and \$600/lane-mile/year were selected to represent low and high PS expenditure levels for OSH flexible pavements, respectively. The corresponding values

for OSH overlaid pavements were $150 and $450/lane-mile/year. Then, the terminal roughness values were used to determine the pavement service life or resurfacing timing under each expenditure level.

The effects of routine maintenance expenditure level on pavement roughness and consequently on resurfacing decisions can be best demonstrated through the examination of the graphical presentation in Figures 7.6 to 7.10. It is clear in these figures that as maintenance expenditure level increases, pavement service life increases. However, the amount of this increase varies. For example, as shown in Figures 7.6 and 7.10, if PS expenditure increased from low to high level, the increase in service life for Interstate and OSH overlaid pavements were about 1 year and 3.3 years, respectively. Based on these results, it can be stated that, regardless of pavement type and region, routine maintenance is more critical in preserving the pavement service life of OSH than that of Interstate pavements.

The results can be used to evaluate the effect of the region on resurfacing needs. It was found that pavements in the northern region need resurfacing earlier than pavements in the southern region. This may be due to the more severe weather in the northern region. As shown in Figures 7.6 and 7.7, at low expenditure level ($200/lane-mile/year)

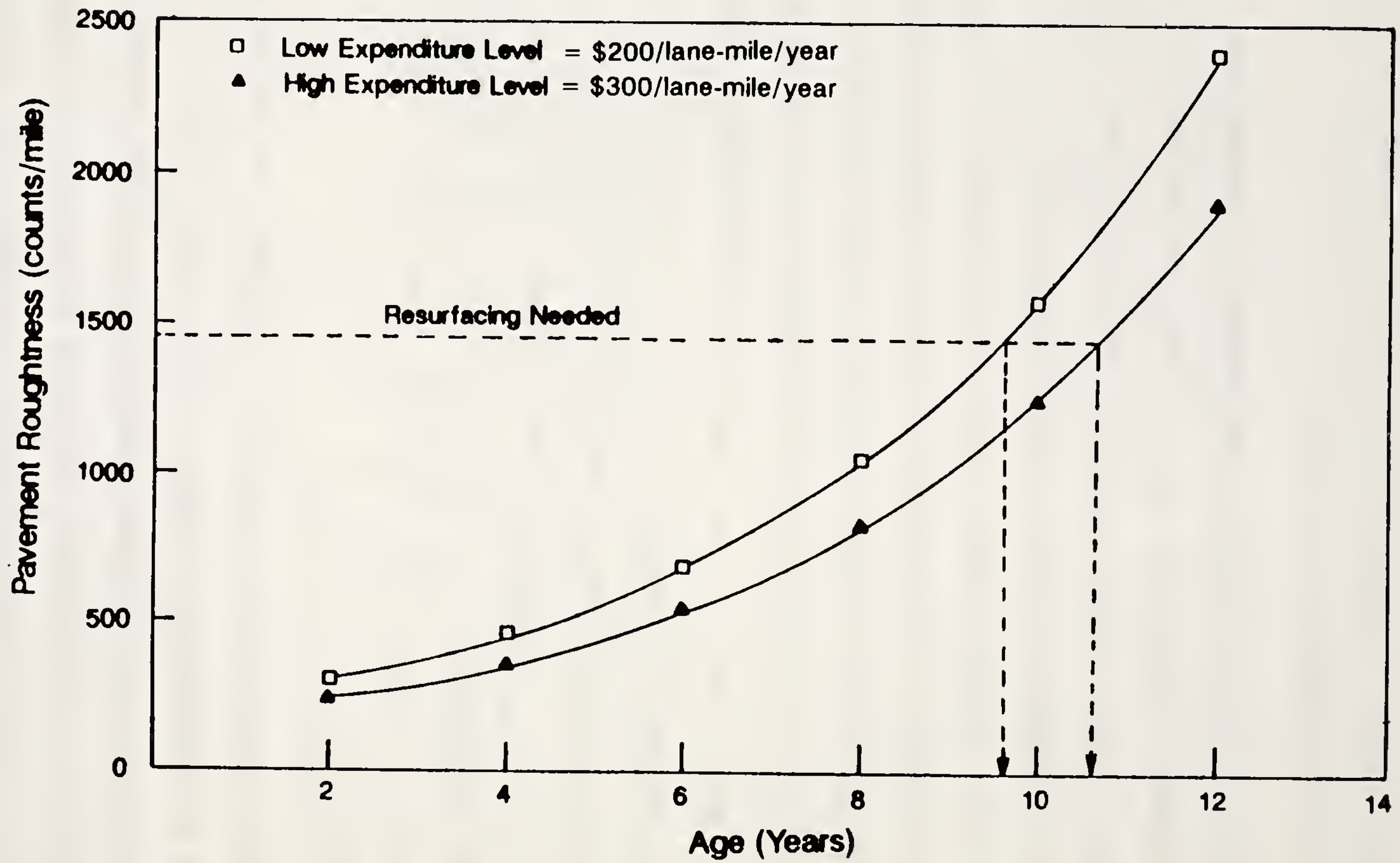


Figure 7.6 Estimated Effect of Patching and Crack Sealing (PS) Expenditure Level on Service Life of Interstate Overlaid Pavement in the Northern Region (Equation 7.6).

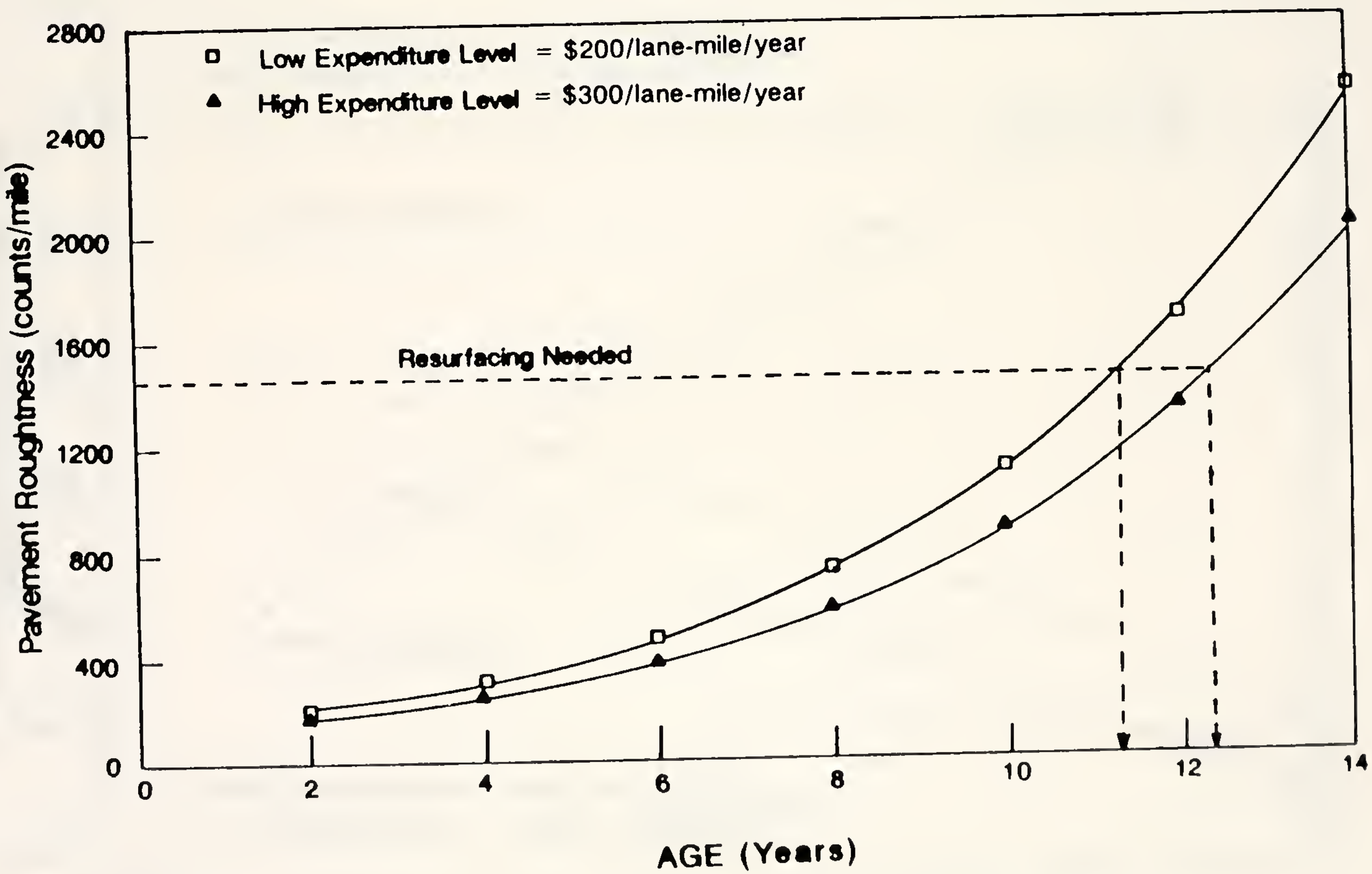


Figure 7.7 Estimated Effect of Patching and Crack Sealing (PS) Expenditure Level on Service Life of Interstate Overlaid Pavement in the Southern Region (Equation 7.6).

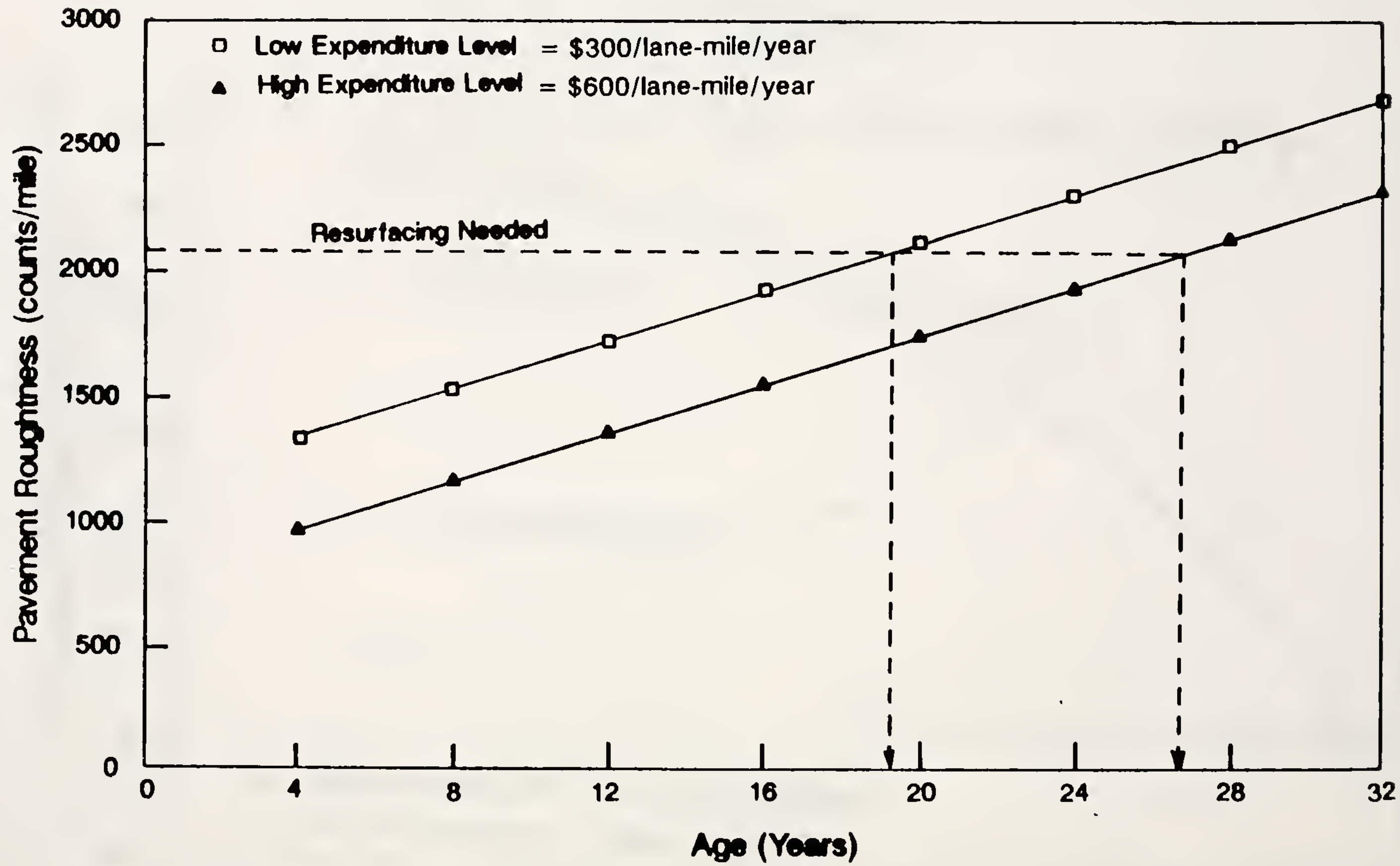


Figure 7.8 Estimated Effect of Patching and Crack Sealing (PS) Expenditure Level on Service Life of OSH Flexible Pavement in the Northern Region - Low Traffic Level (Equation 7.7).

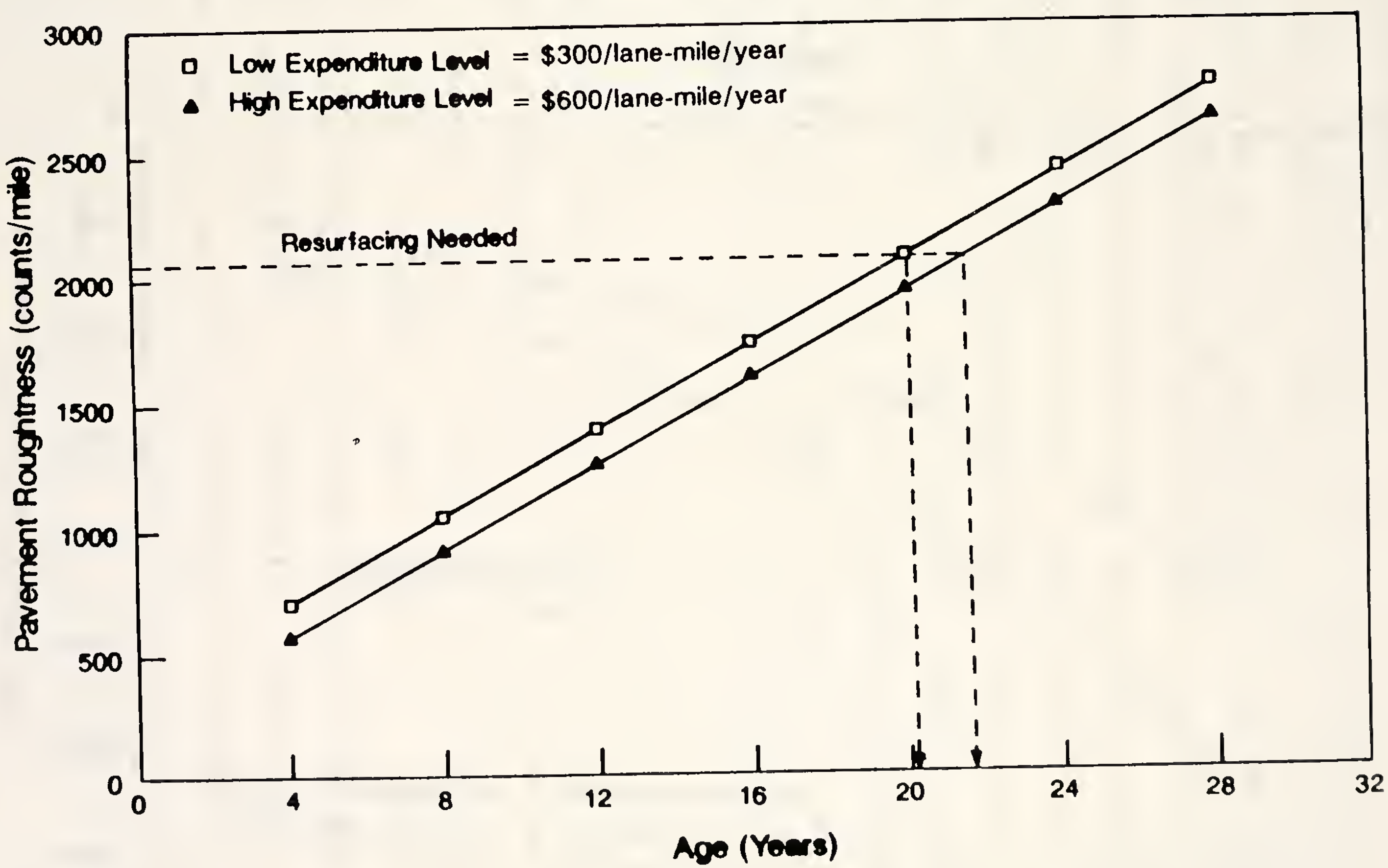


Figure 7.9 Estimated Effect of Patching and Crack Sealing (PS) Expenditure Level on Service Life of OSH Flexible Pavement In the Northern Region - High Traffic Level (Equation 7.8).

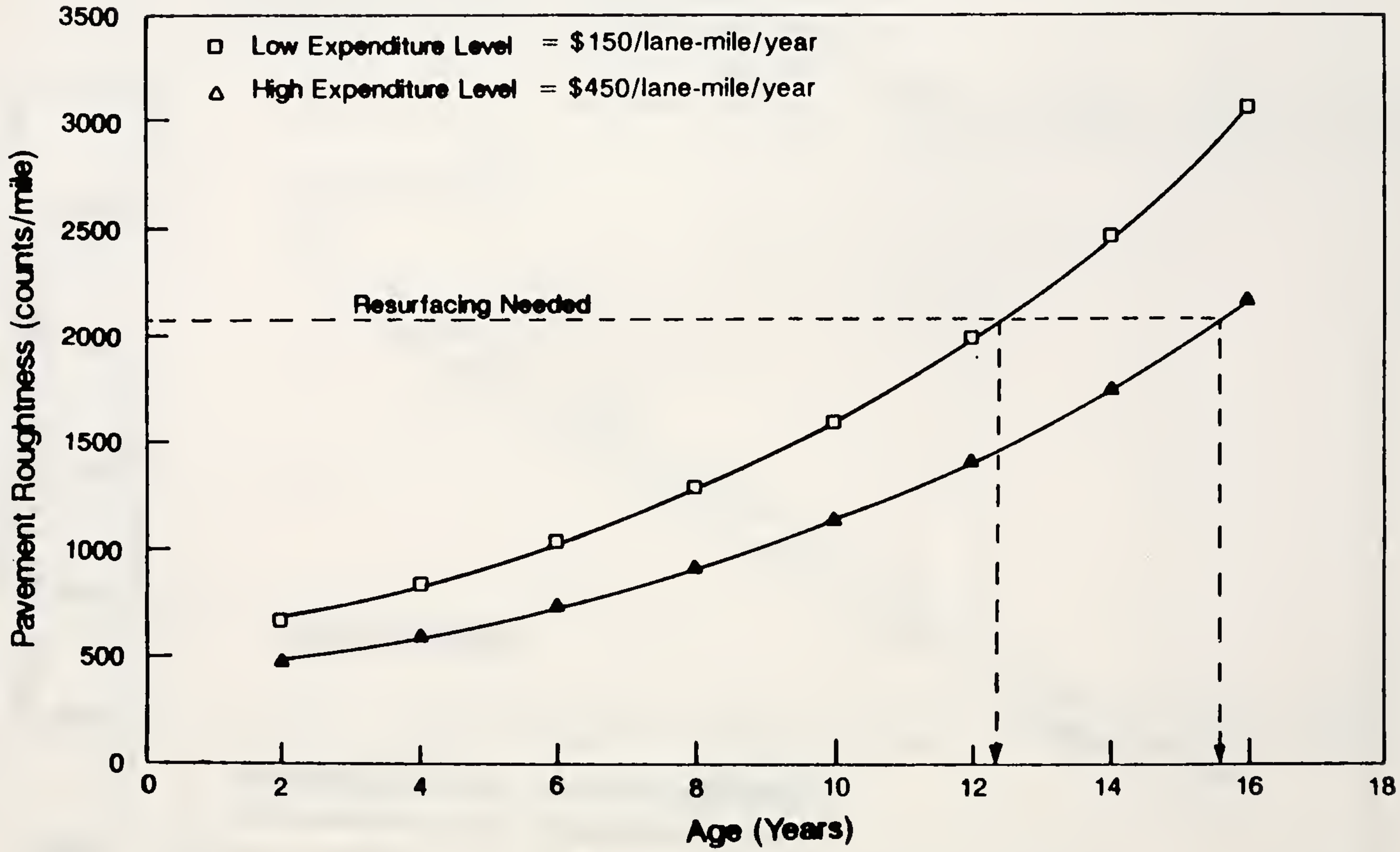


Figure 7.10 Estimated Effect of Patching and Crack Sealing (PS) Expenditure Level on Service Life of OSH Overlaid Pavement in the Northern Region (Equation 7.5).

Interstate overlaid pavements need resurfacing after 9.7 years in the northern region and after 11.4 years in the southern region.

To evaluate the effect of traffic loading levels, Figures 7.8 and 7.9 can be used. If the PS expenditure level increased from \$300 to \$600/lane-mile/year, the increase in service life of OSH flexible pavements for low traffic loading was 8 years, using Equation 7.7. The corresponding value for high traffic loading was 1.6 years using Equation 7.8. The possible reason behind these results is that OSH flexible pavements with high traffic loading may receive more frequent periodic maintenance or resurfacing than those with low traffic loading.

To ensure the applicability of pavement service life prediction models, prediction bands were developed for the effect of each PS expenditure level in Figures 7.6 to 7.10. The standard error of estimates of the model parameters were used to develop these bands. In general, the prediction bands were found wide and they overlapped in the same figure. Moreover, it was noticed that the width of these bands increased as pavement age increased. In other words, the models became less predictable as pavement age increased. Consequently, the results cannot be treated as entirely conclusive.

The results presented in this study are applicable at network level and they cannot be used in actual scheduling of individual resurfacing projects. Resurfacing decisions at the level of individual sections should be based on a comparison of resurfacing cost and routine maintenance cost along with the consideration of appropriate resurfacing design procedures. The results of the present research are applicable to a system wide planning of resurfacing. Furthermore, the prediction models can be employed to provide guidance in the preliminary analysis of pavement life-cycle costing.

To improve the prediction models developed in this chapter, the following factors should be considered:

1. Thickness of overlay.

2. Flexible pavement structural capacity.

3. Rigid pavement slab thickness.

4. Rigid pavement type (jointed plain concrete, jointed reinforced concrete, or continuous reinforced concrete).

5. Resurfacing cost and resurfacing design procedures.

The consideration of these factors would require a comprehensive and extensive data base. However, such a data

base would provide enough information on different pavement contract sections with different ages. Sufficient information on other maintenance activities, such as seal coating and premix leveling, can be obtained by extending the data base to cover more subdistricts and a longer period of study.

7.7 Chapter Summary

In this chapter the effect of routine maintenance expenditure on pavement service life was studied. The nonlinear relationship between pavement roughness and pavement age introduced in the proposed methodology was investigated under different traffic-maintenance expenditure level combinations. The relationship was found linear for flexible and rigid pavements and nonlinear for overlaid pavements.

Further analysis was conducted to decide which was more adequate in representing pavement service life, pavement age or total accumulated ESAL. The results indicated that pavement age was more able to explain the variations in pavement roughness than total accumulated ESAL. Consequently, pavement age can be used as a measure of pavement service life but for a small range of traffic loading.

Prediction models were developed to examine the effect of maintenance expenditure level on pavement service life. The effect of patching expenditure level was found insignificant in all models. The models in which mean annual ESAL was highly significant were re-examined and separate models for low and high traffic levels were developed.

The prediction models were employed to determine the time of resurfacing under low and high expenditure levels of routine maintenance. The results demonstrated that resurfacing can be deferred or postponed by increasing maintenance expenditure level. Routine maintenance was more effective in increasing pavement service life of OSH than Interstate. Also, it was found that pavements in the northern region needed resurfacing earlier than pavements in the southern region.

The prediction bands of the models were wide and it was noticed that the width of these bands increased as pavement age increased. the results of the models, therefore, cannot be treated as entirely conclusive. The models presented are applicable to network level decision-making and should not be used for making resurfacing decisions for individual sections. To improve pavement service life prediction models, other factors such as pavement thickness and cost of resurfacing should be

considered. For that reason, it was recommended to extend the data base to cover more subdistricts and include data over a longer period of time.

CHAPTER 8

SUMMARY AND CONCLUSIONS

8.1 Summary of Proposed Approach

The main objective of this research was to study the effects of routine maintenance expenditure level on pavement surface condition and resurfacing need. To achieve this objective, a methodology for assessing routine maintenance effects was developed. The conceptual framework of this methodology was based on three assumptions: (i) pavement roughness was considered to be a direct aggregate measure of pavement condition; (ii) pavement age at terminal roughness value was taken as a measure of pavement service life for a small range of traffic and for a small variation in climatic condition; and (iii) highway class and pavement type were assumed to represent design standards and construction procedures.

Central to the development of the proposed methodology was the introduction of the following concepts:

1. Interface between Routine Maintenance and Resurfacing - Periodic maintenance activities, such as premix leveling and seal coating, were considered to serve as an interface between basic or annual routine maintenance and resurfacing activities. Premix leveling and seal coating are major maintenance activities with a high degree of impact on pavement condition.

2. Relation between Pavement Age and Level of Routine Maintenance - In this relationship, pavement age was divided into three groups: Age Group I, Age Group II, and Age Group III. The response of pavement condition to routine maintenance level within each age group was illustrated. It was hypothesized that maintenance effectiveness would be highest for Age Group II where pavements are in fair to good condition.

3. Concept of Deterioration in Pavement Surface Condition - Two measures were introduced: (i) rate of change in pavement roughness, and (ii) change in pavement roughness. Pavement age and traffic loading effects were assumed to be implicitly included in the first measure. The second measure was tied with pavement age for a small range of traffic loading, because it was considered an absolute measure of change in pavement surface condition. The purpose of introducing

these measures of deterioration in surface condition was to estimate the effectiveness of different maintenance types for different age groups. Maintenance effectiveness was defined as the reduction in deterioration of surface condition associated with an increase in maintenance expenditure level. Implicit in this definition is the fact that actual maintenance work performed would be less than or equal to the maximum need.

4. Effect of Routine Maintenance Expenditure Level on Pavement Service Life - A relationship between pavement roughness and pavement age as a measure of pavement service life was conceptually introduced under different levels of routine maintenance expenditure. An assumption was made that improvement in pavement condition was positively related to the level of routine maintenance expenditure. The relationship between pavement roughness and pavement age was used to relate pavement resurfacing needs to the level of routine maintenance.

To implement the proposed methodology and accomplish the objectives of this research, a data base for pavement routine maintenance, pavement condition, and pavement characteristics was developed for a selected number of pavement sections from the state highway system in Indiana.

For the sake of efficiency and taking into consideration the recommendations of earlier studies in Indiana [8,12], the data were collected based on contract sections instead of highway sections.

The data base covered ten out of thirty-seven maintenance subdistricts in Indiana. Two highway classes (Interstate and Other State Highways), three pavement types (flexible, rigid, overlaid), and two climatic regions (North and South) were represented in the data base. A total of 550 contract sections were selected including 126 sections in Interstate and the remaining in OSH.

8.2 Summary of Findings

Six pavement routine maintenance activities were considered in this research; shallow patching, deep patching, premix leveling, seal coating, sealing longitudinal cracks and joints, and sealing cracks. The effects of routine maintenance expenditure level on pavement roughness was categorized by activity or group of activities. The major findings of these analyses are summarized below.

1. The use of smaller pavement section unit (contract section) significantly improved the statistical relationship between routine maintenance expenditure

level and pavement roughness.

2. The effects of northern and southern regions on pavement roughness and maintenance expenditure levels were found significant.

3. Regression models were developed for the effects of routine maintenance expenditure level and region on rate of change in pavement roughness. In general, the rate of change in pavement roughness was found more in the northern region, especially at low expenditure levels. Also, the effectiveness of maintenance was higher in those sections receiving both patching and joint and crack sealing than those receiving only patching.

4. Prediction models for surface condition deterioration were developed to relate maintenance effectiveness to pavement age and traffic loading and to improve R^2 of the regression models in Item 3. Change in pavement roughness as an absolute measure of pavement deterioration was used in these models. The results showed that R^2 values of most of the models were significantly improved. Both pavement age and traffic loading factors were found significant in most of the OSH models. However, in Interstate models traffic loading was more significant than pavement age,

possibly because of the relatively narrow age distribution of the interstate sections in the data. The effect of patching expenditure level in most of these models was found insignificant.

5. Maintenance effectiveness for pavements in Age Group II (fair to good condition) was found higher than that for pavements in Age Group I (very good to excellent condition). Maintenance effectiveness for Age Group III was not estimated because the available data on this age group were insufficient. For OSH pavements, maintenance effectiveness for relatively high traffic level was found higher than that for low traffic level. For most of the Interstate models, maintenance effectiveness for low traffic level was found higher than that for high traffic level. This result is probably because Interstate pavements with high traffic level usually receive resurfacing sooner than OSH pavements.

6. The effectiveness of the maintenance category that included premix leveling and seal coating was found noticeable and relatively higher than that of patching and crack sealing category, especially for flexible pavements. This conclusion reflected the possible role of periodic maintenance that are generally performed by contract.

7. The relationship between pavement roughness and pavement age was found linear for flexible and rigid pavements and nonlinear for overlaid pavements. The assumption that pavement age at a terminal roughness value can represent pavement service life was found valid for most of the cases analyzed.

8. Prediction models were developed to examine the effects of routine maintenance expenditure level on pavement service life. Regardless of highway class or pavement type, the effect of patching expenditure level on pavement service life was found insignificant. Also, the effect of routine maintenance expenditure level on service life of rigid pavements was found insignificant. The models that were found significant were employed to relate resurfacing timing to patching and crack sealing expenditure level.

9. On the assumption that the pavement sections considered in specific models were of near homogeneous characteristics, the results can be interpreted that if patching and crack sealing expenditure increases from low to high level, resurfacing can be postponed 1 to 3.3 years for overlaid pavements and 1.6 to 8 years for flexible pavements. Using the same expenditure level in both regions, it was found that pavements in the northern region required resurfacing before

pavements in the southern region. It should be mentioned that the effect of region on resurfacing needs was found significant only for Interstate overlaid pavements.

10. Because the data were not collected from controlled experiments, the results cannot be generalized and they are applicable only with the range of data considered in the study.

8.3 Recommendations for Further Research

Based upon the findings of this study, further research is recommended in the following areas:

1. In general, the R^2 values of the OSH regression models were found relatively low. This resulted from the lack of information on the exact location of maintenance work and from the fact that OSH are not mile-posted. To improve statistically these models, there is a need to tie effectively routine maintenance locations with roughness measurements. For instance, in the case of Indiana, it is recommended to develop a program which can be used to improve the level of training of the maintenance crew members and the degree of supervision during maintenance work. In addition, some means of recording maintenance location on a systematic basis

in all maintenance subdistricts in Indiana can greatly help the monitoring of maintenance activities. This may require among other efforts, mile-posting of Other State Highways.

2. The periods between 1984 and 1985 roughness measurements varied between 8 and 14 months. It was noticed also that pavement roughness for many contract sections decreased without receiving any maintenance or other pavement work during the study period making the accuracy of roughness measurements questionable. To use the roughness measurement records as an efficient aid in making decisions regarding maintenance and resurfacing priorities, the period between two successive roughness measurements should be consistent. Also, it is recommended that roughness measurement devices be calibrated on a routine basis and that roughness measurements within a given year be monitored at many locations within that year and compared to previous years in order to detect possible calibration problems.

3. The relationship between pavement age and level of routine maintenance expenditure has not been well established because of the limited data on pavements especially for Age Group III when pavements are in poor condition. To investigate separately the effects

of routine maintenance on deterioration in pavement surface condition in each of the age groups, the limits or ranges of these groups should be first identified. Then a statistical design of experiment is needed in order to represent each age group using sufficient sample sizes. The range of traffic loading and the variation in climatic conditions should also be considered in this experiment.

4. Effectiveness of premix leveling and seal coating as periodic maintenance activities was implicitly evaluated in this study. To fully investigate the role of periodic maintenance as an interface between basic routine maintenance and resurfacing activities, it is recommended to expand the existing data base to cover more maintenance subdistricts and a longer period of time. A wider data base could also be helpful in analyzing separately the effects of various routine maintenance activities.

5. Pavement service life prediction models in this study were found not precise enough to be used in actual scheduling of individual resurfacing projects. The results of the present study are to be used for network level decision-making. The use of the models at a project level would require the consideration of the effects of other factors such as pavement

thickness, resurfacing cost, and resurfacing design procedures.

6. The analyses conducted in this study are statistical in nature. Therefore, a periodic updating of the results and analysis techniques is needed in order to keep abreast of the changing traffic distribution, changing expenditure pattern, and changing technology. Improvement to the analysis procedures and methodology presented in this study should be made from time to time in order to maintain the consistency of decisions taken at different maintenance management levels.

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APPENDICES

Appendix A

Data Base

Table A.1 Routine Maintenance and Roughness Data.

CON#	HWY	D	T	SD	CO	L.M.	ST	PTCH	SEAL	TOT	RN84	RN85	P84	P85
11241	69	1	1	25	27	18.6	3	94	310	404	745	517	3.1	3.4
11664	69	1	1	25	27	11.6	3	72	0	72	1446	1431	2.5	2.5
13773	69	1	1	25	27	19.6	3	40	0	40	241	205	4.0	4.2
11241	69	2	1	25	27	18.8	3	82	196	278	811	675	3.0	3.2
11664	69	2	1	25	27	11.4	3	92	0	92	2171	2000	2.2	2.2
13773	69	2	1	25	27	19.6	3	24	0	24	220	283	4.1	3.9
12876	69	1	1	24	2	19.2	3	21	0	21	351	390	3.7	3.6
11298	69	1	1	24	17	7.4	3	242	0	242	926	572	2.9	3.3
12876	69	2	1	24	2	19.4	3	54	0	54	452	461	3.5	3.5
11298	69	2	1	24	17	7.2	3	205	0	205	910	670	2.9	3.2
13756	69	1	1	26	35	12.8	3	0	0	0	236	145	4.1	4.5
12322	69	1	1	26	90	21.8	3	12	0	12	393	359	3.6	3.7
12875	69	1	1	23	2	9.8	3	54	0	54	331	284	3.8	3.9
12060	69	1	1	23	2	28.8	3	50	156	206	576	546	3.3	3.3
13756	69	2	1	26	35	12.8	3	0	0	0	209	136	4.2	4.5
12322	69	2	1	26	90	22.0	3	45	0	45	309	311	3.8	3.8
12875	69	2	1	23	2	9.8	3	51	0	51	325	282	3.8	3.9
12060	69	2	1	23	2	28.8	3	46	183	229	533	521	3.4	3.4
13947	69	1	2	34	29	15.2	3	2	0	2	234	301	4.1	3.9
13948	69	1	2	34	48	15.2	3	0	0	0	273	277	3.9	3.9
13902	69	1	2	34	48	12.8	3	0	0	0	270	211	3.9	4.2
13903	69	1	2	34	18	12.4	3	0	0	0	127	155	4.6	4.4
13279	69	1	2	34	18	13.2	3	0	143	143	260	230	4.0	4.1
13287	69	1	2	34	18	15.8	3	50	308	358	176	150	4.3	4.5
13947	69	2	2	34	29	15.2	3	0	0	0	289	356	3.9	3.7
13948	69	2	2	34	48	15.2	3	0	0	0	253	248	4.0	4.0
13902	69	2	2	34	48	12.8	3	0	0	0	291	238	3.9	4.1
13903	69	2	2	34	18	12.8	3	0	0	0	154	177	4.4	4.3
13279	69	2	2	34	18	13.6	3	0	207	207	337	291	3.8	3.9
13287	69	2	2	34	18	14.6	3	88	170	258	260	280	4.0	3.9
11296	65	1	2	53	36	28.8	3	69	103	172	401	441	3.6	3.5
10932	65	1	2	53	3	8.8	3	95	0	95	469	570	3.5	3.3
11297	65	1	2	53	3	15.4	3	104	0	104	369	364	3.7	3.7
11296	65	2	2	53	36	28.2	3	109	93	202	388	383	3.6	3.7
10932	65	2	2	53	3	9.0	3	11	0	11	499	742	3.4	3.1
11297	65	2	2	53	3	15.6	3	63	0	63	343	412	3.7	3.6
13437	74	4	2	53	16	18.6	3	0	78	78	283	337	3.9	3.8
13437	74	5	2	53	16	18.6	3	0	78	78	299	361	3.9	3.8
10734	65	1	2	54	10	4.6	3	203	0	203	1065	1211	2.8	2.7
11237	65	1	2	54	10	14.4	3	130	110	240	614	619	3.2	3.2
10235	65	1	2	54	10	19.4	3	148	0	148	533	525	3.4	3.4

Table A.1 (Continued).

CON#	HWY	D	T	SD	CO	L.M.	ST	PTCH	SEAL	TOT	RN84	RN85	P84	P85
10734	65	2	2	54	10	4.6	3	180	0	180	1107	1386	2.7	2.6
11237	65	2	2	54	10	14.4	3	145	60	205	588	646	3.3	3.2
10235	65	2	2	54	10	19.2	3	121	0	121	558	596	3.3	3.3
12579	70	4	2	11	84	23.6	3	152	68	220	625	291	3.2	3.9
13001	70	4	2	11	11	11.8	3	0	0	0	592	477	3.3	3.5
12579	70	5	2	11	84	23.4	3	39	0	39	631	308	3.2	3.8
13001	70	5	2	11	67	5.0	3	0	0	0	494	426	3.4	3.6
7634	65	1	1	44	37	10.8	2	132	0	132	690	836	3.7	3.5
7246	65	1	1	44	37	6.8	2	8	40	48	944	1332	3.3	2.9
7198	65	1	1	44	37	6.6	2	9	45	54	1062	1492	3.2	2.7
7143	65	1	1	44	37	12.4	2	49	157	206	1082	1293	3.1	2.9
7144	65	1	1	44	37	12.0	2	91	145	236	803	960	3.5	3.3
7116	65	1	1	44	56	12.8	2	99	135	234	817	889	3.5	3.4
6600	65	1	1	44	45	7.0	2	160	0	160	774	792	3.6	3.5
7634	65	2	1	44	37	10.8	2	168	11	179	933	872	3.3	3.4
7246	65	2	1	44	37	6.8	2	50	50	100	1188	1548	3.0	2.7
7198	65	2	1	44	37	6.6	2	40	45	95	1592	2123	2.7	2.3
7143	65	2	1	44	37	12.6	2	31	262	293	960	1122	3.3	3.1
7144	65	2	1	44	37	12.0	2	60	145	205	989	1177	3.3	3.0
7116	65	2	1	44	56	12.8	2	38	18	56	954	1223	3.3	3.0
6600	65	2	1	44	45	7.0	2	160	0	160	1113	1130	3.1	3.1
8476	94	5	1	41	64	7.2	2	21	77	98	714	900	3.7	3.4
8553	94	5	1	41	46	9.0	2	35	80	115	571	899	3.9	3.4
8181	94	5	1	41	46	12.4	2	100	105	205	844	921	3.4	3.3
8476	94	4	1	41	64	6.6	2	205	200	405	1126	1138	3.1	3.1
8553	94	4	1	41	46	9.0	2	115	109	224	891	873	3.4	3.3
8181	94	4	1	41	46	13.0	2	35	40	100	1032	1377	3.2	2.8
7199	69	1	2	34	29	10.8	2	115	50	285	1779	2394	2.5	2.2
7274	69	1	2	34	29	1.0	2	141	87	228	1534	1799	2.6	2.5
7199	69	2	2	34	29	10.8	2	55	50	105	1352	1789	2.9	2.5
7274	69	2	2	34	29	1.0	2	0	87	87	1534	1791	2.6	2.5
7674	65	1	2	53	3	8.2	2	84	0	84	630	731	3.8	3.6
8159	65	1	2	53	73	11.2	2	16	0	16	597	786	3.9	3.5
8221	65	1	2	53	41	8.8	2	119	0	119	1023	1094	3.2	3.1
7912	65	1	2	53	41	9.4	2	33	0	33	992	1076	3.2	3.1
8440	65	1	2	53	41	2.2	2	26	0	26	975	1294	3.2	2.9
7674	65	2	2	53	3	8.2	2	24	0	24	526	675	4.0	3.7
8159	65	2	2	53	73	10.8	2	23	0	23	767	1111	3.6	3.1
8221	65	2	2	53	41	8.8	2	26	0	26	1020	1356	3.2	2.9
7912	65	2	2	53	41	9.6	2	39	0	39	945	1259	3.3	3.0
8440	65	1	2	53	41	3.0	2	8	0	8	1208	1427	3.0	2.8

Table A.1 (Continued).

CON#	HWY	D	T	SD	CO	L.M.	ST	PTCH	SEAL	TOT	RN84	RN85	P84	P85
7421	64	4	2	63	65	7.8	2	0	0	0	600	614	3.9	3.8
7388	64	4	2	63	65	16.6	2	10	0	10	620	661	3.8	3.7
7058	64	4	2	63	65	8.6	2	80	0	80	719	816	3.6	3.5
7056	64	4	2	63	65	7.4	2	0	0	0	798	884	3.5	3.4
7115	64	4	2	63	82	9.0	2	0	0	0	742	816	3.6	3.5
7421	64	5	2	63	65	8.2	2	0	0	0	505	521	4.1	4.0
7388	64	5	2	63	65	16.2	2	0	0	0	641	755	3.8	3.6
7058	64	5	2	63	65	9.0	2	0	0	0	855	1007	3.4	3.2
7056	64	5	2	63	65	7.2	2	0	0	0	751	853	3.6	3.4
7115	64	5	2	63	82	9.4	2	0	0	0	628	659	3.8	3.8
7715	65	2	2	13	79	7.2	2	293	0	293	1577	1708	2.7	2.6
7913	65	2	2	13	79	7.2	2	492	0	492	1000	1209	3.2	3.0
7677	65	2	2	13	79	8.8	2	180	0	180	1910	2416	2.4	2.2
7633	65	2	2	13	79	10.4	2	42	0	42	1445	2198	2.8	2.3
7422	65	2	2	13	91	12.0	2	35	10	45	1372	1747	2.8	2.6
7714	65	2	2	13	91	11.0	2	53	14	67	1455	1789	2.8	2.5
7676	65	2	2	13	91	8.6	2	29	13	42	813	1045	3.5	3.2
7715	65	1	2	13	79	7.2	2	57	0	57	1496	1558	2.7	2.7
7913	65	1	2	13	79	7.2	2	71	0	71	1017	1015	3.2	3.2
7677	65	1	2	13	79	8.8	2	74	0	74	1255	1112	3.0	3.1
7633	65	1	2	13	79	10.4	2	92	0	92	1454	1720	2.8	2.6
7422	65	1	2	13	91	12.0	2	117	90	207	1207	1425	3.0	2.8
7714	65	1	2	13	91	11.0	2	128	42	170	1071	1292	3.2	2.9
7676	65	1	2	13	91	8.6	2	113	38	151	882	709	3.4	3.7
9875	64	5	2	54	13	10.0	2	0	0	0	565	682	3.9	3.7
9617	64	5	2	54	13	18.0	2	14	0	14	917	1002	3.3	3.2
9219	64	5	2	54	31	7.8	2	25	0	25	649	686	3.8	3.7
8311	64	5	2	54	31	16.2	2	27	0	27	466	562	4.2	3.9
7258	64	5	2	54	22	11.8	2	45	256	301	1263	1482	3.0	2.8
5127	64	5	2	54	22	1.0	2	46	0	46	1903	2852	2.4	1.9
9875	64	4	2	54	13	10.6	2	0	0	0	529	574	4.0	3.9
9617	64	4	2	54	13	18.0	2	14	0	14	861	1003	3.4	3.2
9219	64	4	2	54	31	8.8	2	14	0	14	431	470	4.3	4.2
8311	64	4	2	54	31	15.8	2	11	0	11	437	508	4.3	4.1
7258	64	4	2	54	22	10.6	2	46	62	108	1125	1430	3.1	2.8
5127	64	4	2	54	22	1.0	2	46	116	162	2077	2867	2.3	1.9
10033	265	1	2	54	22	14.2	2	0	0	0	948	745	3.3	3.6
10033	265	2	2	54	22	14.2	2	0	0	0	758	678	3.6	3.7
7389	70	4	2	11	84	9.4	2	21	191	212	432	269	4.3	4.9
7145	70	4	2	11	11	9.6	2	0	0	0	1128	323	3.1	4.6
7091	70	4	2	11	11	1.4	2	0	0	0	681	152	3.7	5.0

Table A.1 (Continued).

CON#	HWY	D	T	SD	CO	L.M.	ST	PTCH	SEAL	TOT	RN84	RN85	P84	P85
7389	70	5	2	11	84	9.4	2	0	312	312	415	252	4.1	4.9
7145	70	5	2	11	11	9.4	2	0	0	0	847	262	3.4	4.9
7091	70	5	2	11	11	2.2	2	0	0	0	572	284	3.9	4.8
13472	1	3	5	24	17	10.2	1	208	0	208	441	1129	3.5	2.7
4928	1	3	5	24	17	15.8	1	122	0	122	2668	3754	2.0	1.7
3744	1	3	5	24	76	14.8	1	258	0	258	2294	3621	2.1	1.7
11365	3	3	5	24	44	16.0	1	0	227	227	390	670	3.6	3.2
4928	3	3	5	24	44	12.6	1	142	81	225	1149	1513	2.7	2.5
9391	5	3	5	24	44	2.0	1	17	0	17	464	594	3.5	3.3
12210	5	3	5	24	44	16.0	1	41	27	68	330	548	3.8	3.3
12412	5	3	5	24	44	10.0	1	45	174	219	342	277	3.7	3.9
7358	8	5	5	24	57	5.4	1	104	0	104	1591	2268	2.4	2.1
9035	8	5	5	24	17	2.8	1	73	0	715	637	1022	3.2	2.8
13055	8	5	5	24	17	2.2	1	91	0	91	699	1703	3.1	2.4
13056	8	5	5	24	17	8.3	1	41	0	41	279	669	3.9	3.2
4783	9	3	5	24	44	0.8	1	114	0	114	3063	1951	1.9	2.3
5914	120	4	5	24	76	9.4	1	350	324	674	1589	1621	2.4	2.4
9168	120	4	5	24	76	2.7	1	182	563	745	920	1160	2.9	2.7
9814	120	4	5	24	76	6.7	1	90	0	1443	1576	1460	2.4	2.5
13474	327	2	5	24	17	3.0	1	142	0	142	440	457	3.5	3.5
3877	327	2	5	24	17	5.4	1	310	0	310	3552	2656	1.7	2.0
4672	327	2	5	24	7	6.6	1	240	0	312	2172	2095	2.2	2.1
2	327	2	5	24	76	8.2	1	102	265	367	2298	2279	2.1	2.1
12024	327	2	5	24	76	8.0	1	61	305	1736	673	548	3.2	3.3
11834	427	2	5	24	17	8.2	1	18	204	1492	318	579	3.8	3.3
1	427	2	5	24	76	0.4	1	542	363	2258	1839	1696	2.3	2.4
4928	427	2	5	24	76	5.5	1	166	0	166	1646	2295	2.4	2.1
14935	4	4	5	41	46	2.0	1	17	0	17	693	991	3.1	2.8
12852	4	4	5	41	46	4.5	1	66	0	66	311	447	3.8	3.5
10534	4	4	5	41	46	10.8	1	163	0	163	1115	1387	2.7	2.6
2	8	6	5	41	46	1.0	1	11	0	11	763	2462	3.1	2.1
11221	8	6	5	41	46	15.0	1	6	0	6	613	1505	3.2	2.5
10476	8	6	5	41	75	12.0	1	7	157	164	1267	2359	2.6	2.1
9088	39	3	5	41	75	11.6	1	52	0	1101	1626	2155	2.4	2.2
6895	39	3	5	41	46	4.4	1	0	0	0	612	749	3.3	3.1
6441	39	3	5	41	46	3.0	1	0	0	0	1077	1447	2.8	2.6
13422	39	3	5	41	46	10.8	1	0	0	0	224	114	4.1	4.7
0	104	6	5	41	46	19.0	1	0	0	0	1897	2293	2.3	2.1
13892	10	6	5	44	37	6.8	1	76	325	401	543	748	3.4	3.1
8864	10	6	5	44	37	11.2	1	69	52	121	1636	2095	2.4	2.2
12421	10	6	5	44	37	16.0	1	116	163	279	1128	1828	2.7	2.3

Table A.1 (Continued).

CON#	HWY	D	T	SD	CO	L.M.	ST	PTCH	SEAL	TOT	RN84	RN85	P84	P85
9470	14	6	5	44	56	33.0	1	129	0	129	2751	1049	1.9	2.8
13064	16	4	5	44	37	8.9	1	112	595	707	830	1201	3.0	2.7
11669	16	4	5	44	91	5.7	1	116	304	420	867	1240	3.0	2.6
12634	49	3	5	44	37	23.0	1	0	52	1346	402	680	3.6	3.2
11769	55	3	5	44	56	40.4	1	105	54	159	819	1366	3.0	2.6
12212	55	3	5	44	56	8.8	1	160	313	473	1166	1534	2.7	2.5
9469	55	3	5	44	45	12.6	1	275	0	275	3296	4101	1.8	1.6
12338	114	6	5	44	56	9.8	1	139	0	139	1179	1478	2.7	2.5
10477	114	6	5	44	56	14.6	1	154	0	154	1588	1926	2.4	2.3
10800	114	6	5	44	56	8.0	1	0	0	0	955	1007	2.9	2.8
8092	114	6	5	44	37	7.6	1	48	134	182	1424	1578	2.5	2.4
14816	9	1	5	25	27	3.7	1	64	125	189	443	639	3.5	3.2
4	9	1	5	25	35	5.6	1	6	0	6	885	924	2.9	2.9
4	9	2	5	25	35	5.4	1	6	0	6	821	749	3.0	3.1
10653	13	3	5	25	27	12.4	1	39	0	39	832	1003	3.0	2.8
9400	13	3	5	25	27	8.0	1	39	0	39	1279	1115	2.6	2.7
9006	13	3	5	25	27	11.4	1	57	0	57	857	1029	3.0	2.8
9006	13	3	5	25	85	6.2	1	57	0	57	1033	1347	2.8	2.6
9389	13	3	5	25	85	6.2	1	57	0	57	1206	1109	2.7	2.7
10046	13	3	5	25	85	22.0	1	29	145	174	1195	1619	2.7	2.4
11373	16	4	5	25	9	7.8	1	107	171	278	1306	1617	2.6	2.4
11509	16	4	5	25	52	12.9	1	84	88	172	1709	2234	2.4	2.1
12027	16	4	5	25	85	5.0	1	128	0	1751	628	821	3.2	3.0
91566	16	4	5	25	85	8.9	1	300	0	300	2103	2682	2.2	2.0
91565	16	4	5	25	35	4.9	1	280	0	280	2274	2521	2.1	2.0
14924	18	4	5	25	27	7.2	1	0	0	0	486	422	3.4	3.6
11	18	4	5	25	27	2.3	1	50	0	50	1579	2535	2.4	2.0
11362	105	2	5	25	35	26.7	1	0	285	285	1159	1544	2.7	2.5
11479	124	6	5	25	52	2.2	1	414	330	744	397	214	3.6	4.1
1	124	6	5	25	85	11.6	1	146	0	146	2128	2275	2.2	2.1
1	124	6	5	25	85	14.8	1	129	0	129	1598	1523	2.4	2.5
6879	124	6	5	25	35	7.2	1	0	0	0	1211	1335	2.7	2.6
12849	20	4	3	41	46	3.9	1	59	0	59	380	629	3.7	3.2
6342	35	1	3	41	75	7.9	1	77	0	77	753	685	3.1	3.2
10536	35	1	3	41	75	5.7	1	38	0	38	477	959	3.5	2.9
11420	35	1	3	41	46	0.5	1	444	0	444	1227	1480	2.7	2.5
12337	35	1	3	41	46	5.9	1	0	224	224	429	853	3.6	3.0
9087	231	1	3	44	37	6.1	1	515	0	515	2502	3286	2.0	1.8
9210	31	1	3	25	52	17.0	1	141	0	141	748	864	3.1	3.0
9196	31	1	3	25	52	10.6	1	46	0	46	786	883	3.0	2.9
9210	31	2	3	25	52	16.6	1	131	0	131	607	834	3.3	3.0

Table A.1 (Continued).

CON#	HWY	D	T	SD	CO	L.M.	ST	PTCH	SEAL	TOT	RN84	RN85	P84	P85
9196	31	2	3	25	52	11.2	1	40	0	40	681	840	3.2	3.0
5177	9	1	6	34	48	10.4	1	205	0	205	1461	1881	2.5	2.3
10818	13	3	6	34	30	19.2	1	2	45	427	1396	1356	2.5	2.6
10532	13	3	6	34	48	13.0	1	22	0	22	1418	1176	2.5	2.7
10795	13	3	6	34	29	12.6	1	0	0	0	1662	1542	2.4	2.5
12845	26	4	6	34	27	4.7	1	0	0	0	340	171	3.8	4.3
12846	26	4	6	34	27	3.4	1	0	0	0	565	469	3.3	3.5
10957	26	4	6	34	27	4.1	1	45	0	45	810	687	3.0	3.2
10957	26	4	6	34	27	5.2	1	20	0	20	988	692	2.8	3.1
11369	38	4	6	34	29	7.2	1	48	60	108	547	967	3.3	2.9
9674	38	4	6	34	48	4.0	1	63	0	63	685	1341	3.2	2.6
8673	38	4	6	34	48	1.9	1	228	229	457	1230	2221	2.7	2.1
11840	38	4	6	34	48	9.0	1	0	0	0	559	984	3.3	2.8
8579	9	1	6	53	3	2.8	1	36	0	36	588	717	3.3	3.1
9586	9	1	6	53	3	4.0	1	142	0	142	916	1164	2.9	2.7
11299	9	1	6	53	3	8.6	1	4	0	4	323	543	3.8	3.4
12045	44	5	6	53	41	7.2	1	83	0	83	1441	1375	2.5	2.6
9891	46	5	6	53	3	2.4	1	39	0	39	480	1060	3.5	2.8
5	46	5	6	53	3	3.5	1	179	290	469	1044	1616	2.8	2.4
10187	46	5	6	53	3	1.7	1	175	0	175	499	790	3.4	3.0
10666	46	5	6	53	3	4.6	1	75	0	75	518	592	3.4	3.3
12086	46	5	6	53	3	13.4	1	33	301	375	334	517	3.8	3.4
8679	46	5	6	53	16	4.6	1	15	0	15	852	979	3.0	2.8
5724	46	5	6	53	16	14.7	1	7	0	7	837	1104	3.0	2.7
9891	46	4	6	53	3	2.4	1	39	0	39	963	1452	2.9	2.5
10802	135	3	6	53	41	4.4	1	153	277	430	574	755	3.3	3.1
8906	135	3	6	53	41	9.4	1	153	225	378	615	927	3.2	2.9
10802	135	3	6	53	41	16.0	1	275	272	547	1146	1613	2.7	2.4
13186	252	4	6	53	41	2.6	1	0	0	0	744	777	3.1	3.0
10667	252	4	6	53	73	4.7	1	0	0	0	535	812	3.4	3.0
10370	61	1	6	63	87	10.9	1	21	479	500	662	611	3.2	3.3
2	62	4	6	63	82	3.0	1	717	725	1442	1601	1461	2.4	2.5
13489	65	1	6	63	82	7.3	1	283	298	581	558	497	3.3	3.4
11386	65	1	6	63	65	0.9	1	38	419	457	1184	1942	2.7	2.3
9026	65	1	6	63	26	4.9	1	42	272	314	672	679	3.2	3.2
4360	65	1	6	63	26	5.3	1	101	285	386	675	754	3.2	3.1
10193	69	2	6	63	65	9.0	1	685	145	830	909	640	2.9	3.2
12095	69	2	6	63	65	13.8	1	74	360	434	623	607	3.2	3.3
12215	165	2	6	63	65	3.9	1	99	0	99	569	359	3.3	3.7
13428	165	2	6	63	65	1.9	1	144	0	144	832	573	3.0	3.3
8683	165	2	6	63	65	10.4	1	0	50	50	716	735	3.1	3.1

Table A.1 (Continued).

CON#	HWY	D	T	SD	CO	L.M.	ST	PTCH	SEAL	TOT	RN84	RN85	P84	P85
6352	168	6	6	63	26	15.4	1	33	175	208	585	957	3.3	2.9
6989	168	6	6	63	26	18.8	1	96	307	403	1585	1715	2.5	2.4
10544	261	3	6	63	87	4.8	1	119	0	119	1821	1261	2.3	2.6
11851	261	3	6	63	87	15.4	1	82	0	82	761	638	3.1	3.2
10572	25	3	6	13	79	4.0	1	624	703	1327	1211	906	2.7	2.9
13171	55	3	6	13	86	20.8	1	0	369	369	344	489	3.7	3.4
13084	55	3	6	13	86	9.0	1	101	0	101	319	481	3.8	3.5
13084	55	3	6	13	4	7.0	1	33	352	385	389	673	3.6	3.2
11048	55	3	6	13	4	20.6	1	6	0	1293	419	755	3.6	3.1
0	225	1	6	13	79	2.9	1	94	0	94	1872	2693	2.3	2.0
8995	225	1	6	13	79	1.1	1	93	0	93	1288	1935	2.6	2.3
13470	352	5	6	13	4	8.7	1	0	883	883	425	666	3.6	3.2
11901	3	2	6	54	10	13.3	1	0	116	116	242	589	4.0	3.3
9602	11	2	6	54	31	20.4	1	84	0	84	2180	3577	2.2	1.7
11380	11	2	6	54	31	9.5	1	100	0	100	1275	1586	2.6	2.4
12341	60	6	6	54	88	30.2	1	77	0	77	293	274	3.9	3.9
10478	62	4	6	54	13	15.2	1	71	57	128	437	991	3.5	2.8
14696	62	4	6	54	31	2.1	1	60	152	212	652	1565	3.2	2.4
9022	62	4	6	54	31	14.2	1	70	41	111	671	1455	3.2	2.5
13185	62	4	6	54	10	15.1	1	219	0	219	1287	831	2.7	3.0
11226	64	5	6	54	31	1.0	1	114	0	114	658	1011	3.2	2.8
11226	64	5	6	54	31	4.3	1	80	182	889	707	974	3.1	2.9
7649	111	1	6	54	31	12.5	1	96	309	405	2031	2974	2.2	1.9
10053	111	1	6	54	31	10.8	1	78	0	78	923	1315	2.9	2.6
1	111	1	6	54	22	1.3	1	114	0	114	647	758	3.2	3.1
13286	111	1	6	54	22	2.4	1	95	0	95	312	701	3.8	3.1
11225	111	1	6	54	22	6.6	1	294	0	294	844	1032	3.0	2.8
11379	160	6	6	54	10	16.8	1	0	328	328	2105	1729	2.2	2.4
6187	403	3	6	54	10	11.2	1	20	0	290	667	737	3.2	3.1
4786	462	4	6	54	31	3.0	1	0	0	0	1861	3166	2.3	1.8
12204	42	6	6	11	11	18.4	1	150	0	150	1065	1131	2.8	2.7
14922	42	6	6	11	11	15.6	1	23	0	23	1261	1251	2.6	2.6
10357	46	5	6	11	84	7.4	1	438	0	493	560	226	3.3	4.1
11761	46	5	6	11	60	14.7	1	87	0	87	404	587	3.6	3.3
12208	59	1	6	11	11	12.1	1	45	0	45	1374	1934	2.6	2.3
11046	59	1	6	11	11	0.6	1	1332	0	2685	3781	1885	1.7	2.3
10166	59	1	6	11	11	4.1	1	365	0	365	716	996	3.1	2.8
8873	63	2	6	11	84	8.4	1	60	0	60	1263	1799	2.6	2.3
8880	63	2	6	11	83	14.4	1	107	0	107	681	987	3.2	2.8
6574	63	1	6	11	84	8.4	1	71	0	71	651	352	3.2	3.7
8880	63	1	6	11	84	14.4	1	71	0	71	372	322	3.7	3.8

Table A.1 (Continued).

CON#	HWY	D	T	SD	CO	L.M.	ST	PTCH	SEAL	TOT	RN84	RN85	P84	P85
11360	157	2	6	11	28	13.8	1	194	284	478	1774	1892	2.3	2.3
11659	159	3	6	11	84	23.2	1	186	0	1611	979	855	2.8	3.0
8688	246	4	6	11	84	5.8	1	187	0	187	843	950	3.0	2.9
3580	246	4	6	11	84	7.3	1	84	0	84	1886	1954	2.3	2.3
12205	246	4	6	11	11	6.6	1	164	0	164	989	822	2.8	3.0
12407	246	4	6	11	11	14.8	1	336	333	669	1307	1206	2.6	2.7
11382	31	1	4	53	3	7.0	1	93	41	140	309	805	3.8	3.0
11382	31	2	4	53	3	9.0	1	147	0	152	257	375	4.0	3.7
11068	421	1	4	53	16	3.2	1	175	154	329	403	306	3.6	3.8
8374	421	1	4	53	16	2.0	1	0	0	0	2432	2889	2.1	1.9
5647	150	6	4	54	88	12.8	1	164	0	164	697	852	3.1	3.0
10537	150	6	4	54	31	6.6	1	164	0	164	322	519	3.8	3.4
9994	150	6	4	54	31	21.8	1	177	0	472	837	415	3.0	3.6
10791	1	3	5	24	17	18.2	3	78	0	78	1296	2080	2.6	2.2
11181	8	5	5	24	17	0.9	3	128	0	128	1001	1893	2.8	2.3
12330	9	3	5	24	57	28.4	3	7	0	7	302	658	3.9	3.2
30283	9	3	5	24	44	1.0	3	457	0	457	1809	2657	2.3	2.0
12330	9	3	5	24	44	2.8	3	106	0	106	1203	2839	2.7	1.9
0	427	2	5	24	17	0.5	3	23	124	700	363	826	3.7	3.0
9791	2	5	5	41	46	1.4	3	0	135	135	786	734	3.0	3.1
12527	2	5	5	41	46	12.2	3	0	169	169	479	594	3.5	3.3
11740	2	4	5	41	46	0.4	3	0	130	130	621	998	3.2	2.8
9791	2	4	5	41	46	1.0	3	0	130	130	621	998	3.2	2.8
12527	2	4	5	41	46	12.2	3	0	83	83	622	756	3.2	3.1
11517	10	6	5	44	56	8.0	3	157	0	157	1332	1783	2.6	2.3
11224	16	4	5	44	56	4.1	3	118	71	572	1074	1725	2.8	2.4
8375	16	4	5	44	56	4.7	3	309	0	812	2127	2583	2.2	2.0
10058	16	4	5	44	37	4.2	3	500	0	500	2483	3081	2.1	1.9
10477	16	4	5	44	37	1.7	3	472	205	607	2122	2673	2.2	2.0
11520	114	6	5	44	37	1.2	3	0	135	135	777	1286	3.0	2.6
10358	9	1	5	25	27	6.1	3	161	152	313	1198	1754	2.7	2.4
10471	9	1	5	25	35	4.7	3	62	197	259	921	1148	2.9	2.7
10258	9	1	5	25	35	6.8	3	7	0	7	755	953	3.1	2.9
10258	9	2	5	25	35	6.8	3	5	0	5	621	807	3.2	3.0
11510	13	3	5	25	85	4.6	3	167	0	167	1201	1674	2.7	2.4
11662	13	3	5	25	85	5.8	3	57	225	282	1090	1182	2.8	2.7
8572	18	4	5	25	27	2.5	3	105	0	105	1380	3510	2.6	1.8
11370	18	4	5	25	27	11.0	3	65	0	65	957	1356	2.9	2.6
5	6	5	3	24	17	0.6	3	152	0	152	1200	1099	2.7	2.8
10470	6	5	3	24	17	6.5	3	112	0	112	1050	1239	2.8	2.6
10470	6	5	3	24	17	3.1	3	125	0	125	1214	1294	2.7	2.6

Table A.1 (Continued).

CON#	HWY	D	T	SD	CO	L.M.	ST	PTCH	SEAL	TOT	RN84	RN85	P84	P85
13413	20	4	3	24	44	9.7	3	24	224	248	428	585	3.6	3.3
7038	20	4	3	24	44	11.0	3	43	0	277	1065	1507	2.8	2.5
8894	20	4	3	24	76	11.0	3	263	0	263	1256	1844	2.6	2.3
9669	20	4	3	24	76	9.4	3	23	0	23	1032	1591	2.8	2.4
11898	6	5	3	41	46	11.7	3	44	312	356	815	803	3.0	3.0
11898	6	5	3	41	46	6.0	3	49	0	49	598	630	3.3	3.2
11678	20	5	3	41	46	3.0	3	156	0	156	276	1073	3.9	2.8
8565	20	5	3	41	46	2.7	3	132	139	271	953	1838	2.9	2.3
9989	20	5	3	41	46	1.2	3	190	174	364	1113	1518	2.7	2.5
4	20	5	3	41	46	12.0	3	177	0	177	1120	1589	2.7	2.4
10365	20	5	3	41	46	11.8	3	154	0	154	1195	1644	2.7	2.4
11678	20	4	3	41	46	3.0	3	175	112	287	396	580	3.6	3.3
8565	20	4	3	41	46	2.7	3	128	149	277	1195	2086	2.7	2.2
9989	20	4	3	41	46	12.0	3	128	0	128	848	1334	3.0	2.6
10365	20	4	3	41	46	11.8	3	144	0	144	974	1364	2.9	2.6
11375	35	1	3	41	46	9.2	3	24	293	317	649	1315	3.2	2.6
11375	35	1	3	41	46	4.6	3	124	57	181	1128	1617	2.7	2.4
3319	35	1	3	41	46	8.4	3	129	0	129	1100	1284	2.7	2.6
7837	24	6	3	44	56	9.2	3	378	0	378	1881	475	2.3	3.5
7742	24	6	3	44	56	13.0	3	190	0	190	1279	552	2.6	3.3
13421	24	6	3	44	56	20.6	3	44	53	97	258	798	4.0	3.0
8087	41	1	3	44	56	7.2	3	336	203	539	1708	2064	2.4	2.2
8087	41	2	3	44	56	7.0	3	114	0	114	2068	2910	2.2	1.9
10058	41	2	3	44	56	16.2	3	264	111	375	676	914	3.0	2.9
10058	41	2	3	44	56	2.4	3	257	171	428	1063	1176	2.8	2.7
13419	231	1	3	44	37	2.8	3	0	0	0	596	505	3.3	3.4
8095	231	1	3	44	37	4.2	3	0	0	0	1516	1661	2.5	2.4
9991	231	1	3	44	37	3.2	3	25	191	216	1211	1400	2.7	2.5
11520	231	1	3	44	37	13.2	3	215	40	255	865	848	3.0	3.0
11108	24	5	3	25	85	8.0	3	20	0	20	732	782	3.1	3.0
12329	24	5	3	25	85	15.0	3	107	170	277	480	634	3.5	3.2
11108	24	4	3	25	85	8.0	3	20	0	20	376	613	3.7	3.2
12329	24	4	3	25	85	15.0	3	108	170	278	480	634	3.5	3.2
10114	31	1	3	25	52	19.6	3	135	0	135	760	756	3.1	3.1
10114	31	2	3	25	52	19.6	3	123	0	123	770	710	3.1	3.1
2	9	1	6	34	48	7.2	3	130	137	267	676	826	3.2	3.0
10065	9	1	6	34	48	4.2	3	109	0	109	1264	1524	2.6	2.5
9403	9	1	6	34	48	10.0	3	0	0	0	1355	1935	2.6	2.3
2	9	2	6	34	48	7.2	3	130	217	347	1353	1437	2.6	2.5
10065	9	2	6	34	48	19.2	3	114	0	114	1510	1858	2.5	2.3
11212	13	3	6	34	48	11.8	3	0	0	0	829	868	3.0	3.0

Table A.1 (Continued).

CON#	HWY	D	T	SD	CO	L.M.	ST	PTCH	SEAL	TOT	RN84	RN85	P84	P85
12416	13	3	6	34	48	6.6	3	0	0	0	1332	1735	2.6	2.4
11031	28	6	6	34	48	5.4	3	0	0	21	1694	1194	2.4	2.7
11513	28	6	6	34	48	26.6	3	6	0	10	854	1083	3.1	2.8
14631	32	5	6	34	29	7.6	3	0	0	0	414	415	3.6	3.6
12417	32	5	6	34	48	8.4	3	0	397	397	800	1303	3.0	2.6
14370	32	5	6	34	48	2.0	3	0	218	218	1424	2060	2.5	2.2
5031	32	5	6	34	48	4.6	3	236	0	236	1650	1752	2.4	2.4
13475	109	1	6	34	30	8.8	3	0	267	267	402	471	3.6	3.5
11067	252	4	6	53	41	8.6	3	0	0	0	661	868	3.2	3.0
13189	62	4	6	63	65	6.4	3	18	85	103	397	649	3.6	3.2
12859	62	4	6	63	82	7.0	3	24	178	202	601	1385	3.3	2.6
12858	62	4	6	63	82	2.8	3	228	516	744	746	728	3.1	3.1
12858	62	5	6	63	82	3.0	3	96	174	270	713	1101	3.1	2.7
10482	66	4	6	63	82	5.5	3	98	158	256	1436	2405	2.5	2.1
9308	28	6	6	13	86	28.2	3	154	0	154	1520	2213	2.5	2.2
5150	62	4	6	54	22	10.1	3	177	0	641	1972	1986	2.2	2.2
9409	64	5	6	54	31	10.7	3	86	388	474	1692	1731	2.4	2.4
11065	135	3	6	54	31	24.8	3	123	0	123	791	1109	3.0	2.7
13889	42	6	6	11	84	10.6	3	112	150	262	528	621	3.4	3.2
11828	46	5	6	11	84	3.4	3	30	26	830	688	455	3.2	3.5
9667	46	5	6	11	84	9.8	3	47	352	399	876	833	2.9	3.0
10357	46	4	6	11	84	7.4	3	279	0	334	821	401	3.0	3.6
11203	63	2	6	11	84	13.8	3	74	0	74	984	1648	2.8	2.4
5	31	1	4	53	3	4.2	3	97	262	359	1052	1656	2.8	2.4
10662	31	1	4	53	41	16.8	3	97	0	97	765	868	3.1	3.0
12045	31	1	4	53	41	23.4	3	385	43	460	650	1126	3.2	2.7
5	31	2	4	53	3	6.2	3	74	0	79	890	1454	2.9	2.5
9683	31	2	4	53	31	4.4	3	47	99	146	810	1643	3.0	2.4
10662	31	2	4	53	41	16.8	3	135	60	195	606	1096	3.3	2.8
12045	31	2	4	53	41	23.2	3	383	44	427	695	1129	3.1	2.7
12425	421	1	4	53	69	9.3	3	41	203	244	343	353	3.7	3.7
10207	41	1	4	63	82	12.2	3	14	297	311	744	948	3.1	2.9
10108	41	1	4	63	82	11.2	3	18	207	225	896	1130	2.9	2.7
10109	41	1	4	63	82	10.2	3	29	185	214	733	864	3.1	3.0
11299	41	1	4	63	26	8.8	3	29	0	29	641	798	3.2	3.0
11621	41	1	4	63	26	16.0	3	104	0	104	748	811	3.1	3.0
10207	41	2	4	63	82	11.8	3	28	209	237	747	872	3.1	2.9
10108	41	2	4	63	82	11.4	3	15	106	121	586	1091	3.3	2.8
10109	41	2	4	63	82	9.0	3	65	111	176	529	897	3.4	2.9
11299	41	2	4	63	26	10.0	3	65	0	65	495	823	3.4	3.0
11621	41	2	4	63	26	16.0	3	33	0	33	505	928	3.4	2.9

Table A.1 (Continued).

CON#	HWY	D	T	SD	CO	L.M.	ST	PTCH	SEAL	TOT	RN84	RN85	P84	P85
13410	52	5	4	13	79	12.2	3	46	0	46	409	230	3.6	4.1
7433	52	4	4	13	4	6.8	3	132	0	132	1261	1430	2.6	2.4
7433	52	4	4	13	4	15.4	3	120	153	273	1130	1333	2.7	2.5
4759	52	4	4	13	4	6.4	3	89	0	89	3167	2040	1.8	2.3
13410	52	4	4	13	79	12.2	3	42	0	42	486	207	3.4	4.2
8471	52	4	4	13	79	2.6	3	105	163	268	1346	1510	2.6	2.5
5569	41	2	4	13	86	12.6	3	30	0	30	1585	2387	2.4	2.1
9428	41	2	4	13	86	4.0	3	14	0	14	606	954	3.3	2.9
8066	40	4	4	11	84	9.0	3	101	219	962	1475	1391	2.5	2.5
14047	40	4	4	11	84	4.6	3	7	50	145	486	1006	3.4	2.8
13019	40	4	4	11	84	9.0	3	20	39	104	552	714	3.3	3.1
8556	40	4	4	11	84	10.4	3	67	56	123	761	1222	3.1	2.7
5411	40	4	4	11	11	11.2	3	3	13	16	349	803	3.7	3.0
12630	40	4	4	11	11	14.0	3	86	83	169	573	802	3.4	3.0
8066	40	5	4	11	84	9.0	3	91	232	323	1721	1525	2.4	2.5
14047	40	5	4	11	84	4.6	3	52	57	109	669	790	3.4	3.0
13019	40	5	4	11	84	8.8	3	101	73	174	395	607	3.6	3.3
8556	40	5	4	11	84	10.2	3	115	102	217	896	1195	2.9	2.7
5411	40	5	4	11	11	11.2	3	3	13	16	315	427	3.8	3.6
12630	40	5	4	11	11	14.0	3	41	41	82	374	588	3.7	3.3
12581	41	1	4	11	77	6.4	3	57	100	157	996	1212	2.8	2.7
12582	41	1	4	11	84	14.2	3	110	41	151	1006	1035	2.8	2.8
13168	41	1	4	11	84	1.8	3	526	0	526	1330	3826	2.6	1.7
3	41	1	4	11	84	5.0	3	584	0	584	2099	2477	2.2	2.1
8407	41	1	4	11	84	13.4	3	131	0	131	1353	1490	2.6	2.5
12581	41	2	4	11	77	6.4	3	4	91	95	596	1021	3.3	2.8
12582	41	2	4	11	84	14.0	3	10	168	178	487	903	3.4	2.9
8407	41	2	4	11	84	11.4	3	41	0	41	1116	1180	2.7	2.7
14704	41	2	4	11	61	13.6	3	56	0	56	437	784	3.5	3.0
14630	150	4	4	11	84	7.6	3	45	202	247	693	642	3.1	3.2
8318	150	4	4	11	84	5.3	3	86	443	529	1302	1491	2.6	2.5
4927	9	3	5	24	44	11.4	2	243	0	243	1034	1402	3.2	2.8
5157	2	5	5	41	46	7.0	2	229	0	229	1002	1353	3.2	2.9
5176	2	5	5	41	46	7.0	2	213	0	213	871	950	3.4	3.3
5157	2	4	5	41	46	7.0	2	49	0	49	841	1203	3.5	3.0
5176	2	4	5	41	46	7.0	2	33	0	33	869	966	3.4	3.3
3	9	1	5	25	35	11.6	2	4	0	4	1511	2383	2.7	2.2
3	9	2	5	25	35	11.6	2	4	0	4	1581	2421	2.7	2.2
9061	18	4	5	25	27	3.6	2	76	0	76	956	1437	3.3	2.8
7544	6	5	3	24	57	11.0	2	294	0	294	2699	3415	2.0	1.7
5464	20	5	3	41	46	1.2	2	0	0	0	863	1975	3.4	2.4

Table A.1 (Continued).

CON#	HWY	D	T	SD	CO	L.M.	ST	PTCH	SEAL	TOT	RN84	RN85	P84	P85
4303	30	5	3	41	46	15.2	2	280	0	280	1606	2219	2.4	2.2
4401	30	5	3	41	46	16.8	2	327	154	481	2230	2944	2.1	1.9
4424	30	5	3	41	75	9.8	2	195	62	257	1784	2532	2.5	2.1
4303	30	4	3	41	46	15.6	2	91	0	91	1929	2931	2.3	1.9
4401	30	4	3	41	46	17.0	2	107	0	107	2102	3048	2.2	1.9
4424	30	4	3	41	75	9.0	2	353	0	353	1854	1778	2.5	2.5
5	35	1	3	41	46	2.0	2	89	72	161	1896	2696	2.5	2.0
3567	41	1	3	44	56	11.4	2	213	62	275	2108	3039	2.3	1.9
3721	41	1	3	44	56	9.8	2	192	55	247	2084	3359	2.3	1.7
5524	41	1	3	44	56	16.0	2	183	38	221	1502	2367	2.7	2.2
5919	41	1	3	44	56	13.4	2	187	80	267	1195	1740	3.0	2.6
3797	41	1	3	44	56	10.6	2	583	186	769	2388	3453	2.2	1.7
6	41	2	3	44	56	2.6	2	386	86	472	2303	3180	2.2	1.8
3721	41	2	3	44	56	11.2	2	227	87	314	2045	2927	2.4	1.9
5919	41	2	3	44	56	1.8	2	285	145	430	2196	2343	2.3	2.2
5919	41	2	3	44	56	7.4	2	351	71	422	1481	1944	2.8	2.4
3797	41	2	3	44	56	10.6	2	624	88	712	3173	4203	1.8	1.5
10298	24	5	3	25	52	1.8	2	32	75	107	463	629	4.2	3.8
10303	24	5	3	25	52	12.6	2	34	14	48	516	483	4.1	4.1
10300	24	5	3	25	52	15.4	2	281	0	281	531	654	4.0	3.8
10298	24	4	3	25	52	1.8	2	32	85	117	625	822	3.8	3.5
10303	24	4	3	25	52	12.6	2	34	14	48	561	550	4.0	4.0
10300	24	4	3	25	52	15.4	2	21	0	21	450	649	4.2	3.8
4	32	5	6	34	48	1.7	2	215	0	215	1786	1844	2.5	2.5
6214	46	5	6	53	7	4.2	2	73	134	207	919	1467	3.3	2.8
5090	46	5	6	53	7	5.1	2	74	109	183	818	1462	3.5	2.8
4714	46	5	6	53	3	6.9	2	72	109	181	1175	1840	3.0	2.5
7934	61	1	6	63	87	8.7	2	0	217	217	1092	1319	3.1	2.9
0	62	4	6	63	65	2.4	2	178	109	287	788	832	3.0	2.9
10233	62	4	6	63	65	10.2	2	0	95	95	698	997	3.7	3.2
10234	62	4	6	63	65	11.6	2	0	104	104	706	1087	3.7	2.8
3750	62	4	6	63	82	1.8	2	97	48	145	180	628	5.0	3.8
7697	62	5	6	63	65	2.6	2	0	208	208	1180	1389	3.0	2.8
10233	62	5	6	63	65	10.8	2	0	109	109	532	651	4.0	3.8
8878	62	5	6	63	65	4.8	2	0	109	109	957	1582	3.3	2.7
10234	62	5	6	63	65	4.2	2	19	185	204	514	754	4.1	3.6
8807	62	5	6	63	82	6.8	2	34	156	190	1288	2011	2.9	2.4
3750	62	5	6	63	82	3.2	2	640	408	1048	974	999	3.3	3.2
7625	66	4	6	63	65	8.4	2	0	192	192	1103	1580	3.1	2.7
7689	66	4	6	63	82	5.2	2	183	135	318	857	1178	3.4	3.1
5202	66	4	6	63	82	4.4	2	264	46	310	1971	1583	2.4	2.7

Table A.1 (Continued).

CON#	HWY	D	T	SD	CO	L.M.	ST	PTCH	SEAL	TOT	RN84	RN85	P84	P85
5460	66	4	6	63	82	2.4	2	166	48	214	879	1238	3.4	3.1
1	66	4	6	63	87	6.2	2	127	552	679	1445	2548	2.8	2.1
7625	66	5	6	63	65	8.4	2	0	383	383	846	1231	3.4	3.0
7689	66	5	6	63	82	5.4	2	192	424	616	948	1267	3.3	2.9
5202	66	5	6	63	82	4.4	2	173	53	226	1443	2202	2.8	2.3
5460	66	5	6	63	82	2.4	2	547	60	607	1090	1453	3.1	2.8
10319	26	6	6	13	79	3.8	2	195	0	195	987	1092	3.3	3.1
10674	63	1	6	13	86	8.0	2	0	0	0	910	966	3.4	3.4
10495	63	1	6	13	86	9.6	2	0	0	0	671	645	3.7	3.8
10494	63	1	6	13	86	11.2	2	192	357	549	877	928	3.4	3.3
9874	63	1	6	13	86	3.8	2	215	443	658	1430	1479	2.8	2.8
10674	63	2	6	13	86	6.8	2	0	0	0	925	1050	3.3	3.2
10495	63	2	6	13	86	9.6	2	0	0	0	739	985	3.6	3.3
10494	63	2	6	13	86	9.2	2	138	299	437	639	805	3.8	3.5
9874	63	2	6	13	86	5.8	2	220	475	695	1269	1590	2.9	2.7
4723	3	2	6	54	10	2.4	2	0	1535	1699	1675	1845	2.6	2.5
4715	64	5	6	54	13	3.2	2	250	0	250	1370	1692	2.6	2.4
4715	64	5	6	54	31	2.5	2	228	0	228	2172	2630	2.2	2.0
7218	135	3	6	54	31	6.6	2	162	0	162	1348	2117	2.9	2.3
7879	135	3	6	54	31	13.4	2	162	0	162	1169	1893	3.0	2.5
8222	135	3	6	54	31	12.0	2	240	0	240	1053	1344	3.2	2.9
3788	59	1	6	11	11	7.0	2	182	0	182	1109	1339	3.1	2.9
2	63	2	6	11	84	3.5	2	114	0	114	1413	2162	2.5	2.3
4	31	1	4	53	3	6.2	2	83	120	209	618	1308	3.2	2.6
8650	41	1	4	63	82	4.8	2	214	0	214	1425	1697	2.8	2.6
8313	41	1	4	63	82	4.0	2	206	0	206	1261	1620	3.0	2.6
8650	41	2	4	63	82	5.0	2	73	0	73	2130	1481	2.3	2.8
8313	41	2	4	63	82	3.8	2	75	0	75	1775	1479	2.5	2.8
6959	52	5	4	13	4	4.8	2	31	0	31	1375	2182	2.8	2.3
5044	52	5	4	13	4	5.0	2	129	26	155	1938	2827	2.4	2.0
6958	52	5	4	13	4	14.6	2	189	42	231	1254	1656	3.0	2.6
3786	52	5	4	13	4	5.4	2	289	0	289	1918	2260	2.4	2.3
3408	52	5	4	13	4	5.8	2	247	0	247	1754	1940	2.5	2.4
4	52	5	4	13	4	9.4	2	107	0	107	1613	1539	2.7	2.8
9893	52	5	4	13	79	4.4	2	5	0	5	1327	1786	2.9	2.5
8471	52	5	4	13	79	3.0	2	215	106	321	1851	2204	2.5	2.3
8347	52	5	4	13	79	2.6	2	290	0	290	1651	1623	2.6	2.6
7635	52	5	4	13	79	3.8	2	982	0	982	2163	2071	2.3	2.3
5044	52	4	4	13	4	2.6	2	66	29	95	3413	2591	1.7	2.1
3786	52	4	4	13	4	5.2	2	88	0	88	2828	2780	2.0	2.2
1	52	4	4	13	4	9.4	2	113	0	113	1702	1516	2.6	2.7

Table A.1 (Continued).

CON#	HWY	D	T	SD	CO	L.M.	ST	PTCH	SEAL	TOT	RN84	RN85	P84	P85
9893	52	4	4	13	79	4.4	2	49	0	49	1256	1436	3.0	2.8
8347	52	4	4	13	79	2.6	2	259	123	382	1651	1889	2.6	2.5
7635	52	4	4	13	79	3.8	2	649	0	649	2163	2560	2.3	2.1
9569	41	1	4	13	86	17.4	2	33	16	49	924	852	3.3	3.4
9428	41	1	4	13	86	11.4	2	222	45	267	1702	1959	2.6	2.4
8182	41	1	4	13	4	17.2	2	250	415	665	1957	2418	2.4	2.2
9569	41	2	4	13	86	17.8	2	42	15	57	1024	1250	3.2	3.0
9569	41	2	4	13	86	2.2	2	16	0	16	1188	1660	3.0	2.6
9428	41	2	4	13	4	5.2	2	26	27	53	1252	1611	3.0	2.7
9908	41	2	4	13	4	16.6	2	74	133	207	663	829	3.7	3.5
6912	150	6	4	54	22	28.4	2	99	0	99	1224	1749	3.0	2.6
4	41	1	4	11	84	1.0	2	160	0	160	1613	3643	2.7	1.6
13636	41	1	4	11	84	0.8	2	164	0	164	1313	2585	2.6	2.0
4	41	1	4	11	84	3.4	2	212	0	212	1862	2070	2.5	2.3
2	41	2	4	11	84	4.8	2	704	0	704	2147	2103	2.2	2.2
13636	41	1	4	11	84	1.0	2	993	0	993	2502	3601	2.0	1.7
2	41	2	4	11	84	2.0	2	759	0	759	2428	2533	2.0	2.0

Table A.2 Traffic and Pavement Characteristics Data.

CON#	HWY	D	T	SD	CO	L.M.	S	YR	YRS	THIK	PTR	TOTADT	ADT	TESAL	ESAL
11241	69	1	1	25	27	18.6	3	78	0	4.4	30.0	26562	3794	1324	189
11664	69	1	1	25	27	11.6	3	78	0	0.8	30.0	21092	3013	1050	150
13773	69	1	1	25	27	19.6	3	83	0	4.4	31.2	5088	2544	268	134
11241	69	2	1	25	27	18.8	3	78	0	4.4	30.0	26562	3794	1324	189
11664	69	2	1	25	27	11.4	3	78	0	0.8	30.0	21092	3013	1050	150
13773	69	2	1	25	27	19.6	3	83	0	4.4	31.2	5088	2544	268	134
12876	69	1	1	24	2	19.2	3	81	0	4.4	35.5	12261	3065	725	181
11298	69	1	1	24	17	7.4	3	78	0	4.4	36.0	25320	3617	1513	216
12876	69	2	1	24	2	19.4	3	81	0	4.4	35.5	12261	3065	725	181
11298	69	2	1	24	17	7.2	3	78	0	4.4	36.0	25320	3617	1513	216
13756	69	1	1	26	35	12.8	3	83	0	4.2	32.4	5116	2558	288	140
12322	69	1	1	26	90	21.8	3	80	0	4.4	33.7	15876	3175	889	178
12875	69	1	1	23	2	9.8	3	81	0	4.4	35.0	14356	3589	838	210
12060	69	1	1	23	2	28.8	3	80	0	4.3	19.1	27238	5447	864	173
13756	69	2	1	26	35	12.8	3	83	0	4.2	32.4	5116	2558	288	140
12322	69	2	1	26	90	22.0	3	80	0	4.4	33.7	15876	3175	889	178
12875	69	2	1	23	2	9.8	3	81	0	4.4	35.0	14356	3589	838	210
12060	69	2	1	23	2	28.8	3	80	0	4.3	19.1	27238	5447	864	173
13947	69	1	2	34	29	15.2	3	83	0	4.4	28.0	8855	4427	418	209
13948	69	1	2	34	48	15.2	3	83	0	4.4	19.0	8361	4180	268	134
13902	69	1	2	34	48	12.8	3	83	0	4.4	26.0	6489	3244	285	142
13903	69	1	2	34	18	12.4	3	83	0	4.4	27.0	7193	3596	327	164
13279	69	1	2	34	18	13.2	3	82	0	4.4	27.0	10444	3481	476	159
13287	69	1	2	34	18	15.8	3	82	0	4.4	28.5	10364	3454	498	166
13947	69	2	2	34	29	15.2	3	83	0	4.4	28.0	8855	4427	418	209
13948	69	2	2	34	48	15.2	3	83	0	4.4	19.0	8361	4180	268	134
13902	69	2	2	34	48	12.8	3	83	0	4.4	26.0	6489	3244	285	142
13903	69	2	2	34	18	12.8	3	83	0	4.4	27.0	7193	3596	327	164
13279	69	2	2	34	18	13.6	3	82	0	4.4	27.0	10444	3481	476	159
13287	69	2	2	34	18	14.6	3	82	0	4.4	28.5	10634	3454	498	166
11296	65	1	2	53	36	28.8	3	79	0	4.3	31.0	31668	5278	1630	272
10932	65	1	2	53	3	8.8	3	77	0	4.3	18.0	42181	5272	1265	158
11297	65	1	2	53	3	15.4	3	79	0	4.4	18.0	26350	4391	787	131
11296	65	2	2	53	36	28.2	3	79	0	4.3	31.0	31668	5278	1630	272
10932	65	2	2	53	3	9.0	3	77	0	4.3	18.0	42181	5272	1265	158
11297	65	2	2	53	3	15.6	3	79	0	4.3	18.0	26350	4391	787	131
13437	74	4	2	53	16	18.6	3	83	0	4.2	22.0	5873	2936	218	109
13437	74	5	2	53	16	18.6	3	83	0	4.2	22.0	5873	2936	218	109
10734	65	1	2	54	10	4.6	3	78	0	3.6	18.0	109717	15673	3280	469
11237	65	1	2	54	10	14.4	3	78	0	3.6	18.0	63908	9129	1911	273
10235	65	1	2	54	10	19.4	3	77	0	3.8	31.0	50685	6335	2618	327

Table A.2 (Continued).

CON#	HWY	D	T	SD	CO	L.M.	S	YR	YRS	THIK	PTR	TOTADT	ADT	TESAL	ESAL
10734	65	2	2	54	10	4.6	3	78	0	3.6	18.0	109717	15673	3280	469
11237	65	2	2	54	10	14.4	3	78	0	3.6	18.0	63908	9129	1911	273
10235	65	2	2	54	10	19.2	3	77	0	3.8	31.0	50685	6335	2618	327
12579	70	4	2	11	84	23.6	3	81	0	4.3	23.9	17956	4489	716	179
13001	70	4	2	11	11	11.8	3	81	0	4.2	36.5	19280	4820	1173	293
12579	70	5	2	11	84	23.4	3	81	0	4.3	23.9	17956	4489	716	179
13001	70	5	2	11	67	5.0	3	81	0	4.2	36.5	19280	4820	1173	293
7634	65	1	1	44	37	10.8	2	68	0	9.0	39.0	69310	4077	6848	403
7246	65	1	1	44	37	6.8	2	68	0	10.0	39.0	67139	3949	6633	390
7198	65	1	1	44	37	6.6	2	68	0	10.0	39.0	67139	3949	6633	390
7143	65	1	1	44	37	12.4	2	68	0	10.0	39.0	68030	4001	6720	395
7144	65	1	1	44	37	12.0	2	68	0	10.0	39.0	67876	3992	6705	394
7116	65	1	1	44	56	12.8	2	68	0	10.0	33.5	94199	5541	7996	470
6600	65	1	1	44	45	7.0	2	66	0	10.0	29.5	93187	5481	6965	410
7634	65	2	1	44	37	10.8	2	68	0	9.0	39.0	69310	4077	6848	403
7246	65	2	1	44	37	6.8	2	68	0	10.0	39.0	67139	3949	6633	390
7198	65	2	1	44	37	6.6	2	68	0	10.0	39.0	67139	3949	6633	390
7143	65	2	1	44	37	12.6	2	68	0	10.0	39.0	68031	4001	6720	395
7144	65	2	1	44	37	12.0	2	68	0	10.0	39.0	67876	3992	6705	394
7116	65	2	1	44	56	12.8	2	68	0	10.0	33.5	94199	5541	7996	470
6600	65	2	1	44	45	7.0	2	66	0	10.0	29.5	93187	5481	6965	410
8476	94	5	1	41	64	7.2	2	70	0	9.0	25.0	131768	8784	8348	557
8553	94	5	1	41	46	9.0	2	71	0	9.0	25.0	113187	8084	7169	512
8181	94	5	1	41	46	12.4	2	69	0	9.0	27.5	109022	6813	7600	475
8476	94	4	1	41	64	6.6	2	70	0	9.0	25.0	131768	8784	8348	557
8553	94	4	1	41	46	9.0	2	71	0	9.0	25.0	113187	8084	7169	512
8181	94	4	1	41	46	13.0	2	69	0	9.0	27.5	109022	6813	7600	475
7199	69	1	2	34	29	10.8	2	68	0	10.0	31.0	81793	4811	6431	378
7274	69	1	2	34	29	1.0	2	69	0	10.0	31.0	81954	5122	6443	403
7199	69	2	2	34	29	10.8	2	68	0	10.0	31.0	81793	4811	6431	378
7274	69	2	2	34	29	1.0	2	69	0	10.0	31.0	81954	5122	6443	403
7674	65	1	2	53	3	8.2	2	70	0	8.0	31.0	78108	5207	6136	409
8159	65	1	2	53	73	11.2	2	71	0	8.0	31.0	75855	5418	5957	426
8221	65	1	2	53	41	8.8	2	71	0	8.0	31.0	82652	5903	6490	464
7912	65	1	2	53	41	9.4	2	71	0	9.0	31.0	89581	6398	7037	503
8440	65	1	2	53	41	2.2	2	72	0	9.0	31.0	118535	9118	9302	716
7674	65	2	2	53	3	8.2	2	70	0	8.0	31.0	78108	5207	6136	409
8159	65	2	2	53	73	10.8	2	71	0	8.0	31.0	75855	5418	5957	426
8221	65	2	2	53	41	8.8	2	71	0	8.0	31.0	82652	5903	6490	464
7912	65	2	2	53	41	9.6	2	71	0	9.0	31.0	89581	6398	7037	503
8440	65	1	2	53	41	3.0	2	72	0	9.0	31.0	118535	9118	9302	716

Table A.2 (Continued).

CON#	HWY	D	T	SD	CO	L.M.	S	YR	YRS	THIK	PTR	TOTADT	ADT	TESAL	ESAL
7421	64	4	2	63	65	7.8	2	67	0	10.0	31.0	34118	1895	2682	149
7388	64	4	2	63	65	16.6	2	67	0	10.0	31.0	31011	1722	2436	135
7058	64	4	2	63	65	8.6	2	66	0	10.0	31.0	33194	1747	2607	137
7056	64	4	2	63	65	7.4	2	66	0	10.0	34.0	35716	1879	3077	162
7115	64	4	2	63	82	9.0	2	69	0	10.0	37.0	30970	1935	2904	181
7421	64	5	2	63	65	8.2	2	67	0	10.0	31.0	34118	1895	2682	149
7388	64	5	2	63	65	16.2	2	67	0	10.0	31.0	31011	1722	2436	135
7058	64	5	2	63	65	9.0	2	66	0	10.0	31.0	33194	1747	2607	137
7056	64	5	2	63	65	7.2	2	66	0	10.0	34.0	35716	1879	3077	162
7115	64	5	2	63	82	9.4	2	69	0	10.0	37.0	30970	1935	2904	181
7715	65	2	2	13	79	7.2	2	70	0	9.0	26.5	89790	5986	6025	402
7913	65	2	2	13	79	7.2	2	71	0	9.0	18.0	82136	5866	3848	275
7677	65	2	2	13	79	8.8	2	70	0	9.0	35.0	78922	5261	6993	466
7633	65	2	2	13	79	10.4	2	70	0	9.0	36.0	63484	4232	5789	386
7422	65	2	2	13	91	12.0	2	71	0	9.0	37.0	59500	4250	5577	398
7714	65	2	2	13	91	11.0	2	70	0	9.0	37.0	60759	4050	5695	380
7676	65	2	2	13	91	8.6	2	70	0	9.0	38.0	62567	4171	6021	401
7715	65	1	2	13	79	7.2	2	70	0	9.0	26.5	89790	5986	6025	402
7913	65	1	2	13	79	7.2	2	71	0	9.0	18.0	82136	5866	3848	275
7677	65	1	2	13	79	8.8	2	70	0	9.0	35.0	78922	5261	6993	466
7633	65	1	2	13	79	10.4	2	70	0	9.0	36.0	63484	4232	5789	386
7422	65	1	2	13	91	12.0	2	71	0	9.0	37.0	59500	4250	5577	398
7714	65	1	2	13	91	11.0	2	70	0	9.0	37.0	60759	4050	5695	380
7676	65	1	2	13	91	8.6	2	70	0	9.0	38.0	62567	4171	6021	401
9875	64	5	2	54	13	10.0	2	75	0	11.0	32.0	27642	2764	2237	224
9617	64	5	2	54	13	18.0	2	75	0	11.0	32.0	27999	2799	2265	226
9219	64	5	2	54	31	7.8	2	72	0	10.0	32.0	42142	3241	3412	262
8311	64	5	2	54	31	16.2	2	72	0	10.0	32.0	43404	3338	3514	270
7258	64	5	2	54	22	11.8	2	69	0	10.0	27.8	100610	6288	7086	443
5127	64	5	2	54	22	1.0	2	69	0	10.0	11.0	118123	7382	3288	206
9875	64	4	2	54	13	10.6	2	75	0	11.0	32.0	27642	2764	2237	224
9617	64	4	2	54	13	18.0	2	75	0	11.0	32.0	27999	2799	2265	226
9219	64	4	2	54	31	8.8	2	72	0	10.0	32.0	42142	3241	3412	262
8311	64	4	2	54	31	15.8	2	72	0	10.0	32.0	43404	3338	3514	270
7258	64	4	2	54	22	10.6	2	69	0	10.0	27.8	100610	6288	7086	443
5127	64	4	2	54	22	1.0	2	69	0	10.0	11.0	118123	7382	3288	206
10033	265	1	2	54	22	14.2	2	76	0	11.0	22.0	27922	3102	1550	172
10033	265	2	2	54	22	14.2	2	76	0	11.0	22.0	27922	3102	1550	172
7389	70	4	2	11	84	9.4	2	70	0	10.0	25.5	84927	5661	5491	366
7145	70	4	2	11	11	9.6	2	70	0	10.0	36.0	80063	5337	7310	487
7091	70	4	2	11	11	1.4	2	69	0	10.0	36.0	85449	5340	7802	488

Table A.2 (Continued).

CON#	HWY	D	T	SD	CO	L.M.	S	YR	YRS	THIK	PTR	TOTADT	ADT	TESAL	ESAL
7389	70	5	2	11	84	9.4	2	70	0	10.0	25.5	84927	5661	5491	366
7145	70	5	2	11	11	9.4	2	69	0	10.0	36.0	80063	5337	7310	487
7091	70	5	2	11	11	2.2	2	69	0	10.0	36.0	85449	5340	7802	488
13472	1	3	5	24	17	10.2	1	83	0	1.3	15.0	3721	1860	65	32
4928	1	3	5	24	17	15.8	1	60	78	1.0	15.0	7686	307	128	5
3744	1	3	5	24	76	14.8	1	54	82	1.0	13.0	10714	357	158	5
11365	3	3	5	24	44	16.0	1	78	0	0.6	12.0	7550	1078	92	13
4928	3	3	5	24	44	12.6	1	58	83	1.0	12.0	5798	214	78	3
9391	5	3	5	24	44	2.0	1	71	81	1.5	12.0	10670	762	140	10
12210	5	3	5	24	44	16.0	1	81	0	1.0	12.0	5835	1458	76	19
12412	5	3	5	24	44	10.0	1	80	0	1.0	12.0	10097	2019	128	26
7358	8	5	5	24	57	5.4	1	67	79	1.5	14.3	18708	1039	305	17
9035	8	5	5	24	17	2.8	1	72	79	0.8	15.0	27094	2084	448	34
13055	8	5	5	24	17	2.2	1	81	0	1.3	10.8	11933	2983	126	32
13056	8	5	5	24	17	8.3	1	81	83	2.0	15.0	1423	355	21	5
4783	9	3	5	24	44	0.8	1	59	84	1.0	25.0	48814	1877	1365	52
5914	120	4	5	24	76	9.4	1	63	78	1.5	13.0	16923	769	248	11
9168	120	4	5	24	76	2.7	1	73	83	0.8	13.0	20409	1700	280	23
9814	120	4	5	24	76	6.7	1	56	79	1.5	13.0	14772	509	218	8
13474	327	2	5	24	17	3.0	1	82	0	1.3	15.0	8251	2750	143	48
3877	327	2	5	24	17	5.4	1	64	79	1.0	15.0	14467	688	249	12
4672	327	2	5	24	7	6.6	1	59	0	1.0	15.0	9828	378	169	7
2	327	2	5	24	76	8.2	1	58	81	1.0	13.0	10722	397	159	6
12024	327	2	5	24	76	8.0	1	79	0	0.7	3.0	3520	586	43	7
11834	427	2	5	24	17	8.2	1	79	0	0.6	15.0	3942	657	54	9
1	427	2	5	24	76	0.4	1	74	0	1.5	13.0	15479	1407	214	19
4928	427	2	5	24	76	5.5	1	60	81	1.0	13.0	8966	358	134	5
14935	4	4	5	41	46	2.0	1	84	0	1.0	7.0	3428	3428	20	20
12852	4	4	5	41	46	4.5	1	81	0	1.3	9.7	7380	1845	73	19
10534	4	4	5	41	46	10.8	1	76	0	1.1	10.0	6289	698	65	7
2	8	6	5	41	46	1.0	1	38	0	1.5	10.0	22097	736	250	8
11221	8	6	5	41	46	15.0	1	78	84	1.0	10.0	5749	821	55	8
10476	8	6	5	41	75	12.0	1	76	0	1.0	11.0	3522	391	40	4
9088	39	3	5	41	75	11.6	1	64	82	1.6	10.5	14511	691	174	8
6895	39	3	5	41	46	4.4	1	66	0	2.8	14.1	44642	2349	675	36
6441	39	3	5	41	46	3.0	1	64	0	3.0	13.0	44851	2135	663	32
13422	39	3	5	41	46	10.8	1	82	0	1.0	13.0	4298	1432	65	22
0	104	6	5	41	46	19.0	1	61	82	1.0	10.0	12409	517	142	6
13892	10	6	5	44	37	6.8	1	83	0	1.9	21.0	2470	1235	60	30
8864	10	6	5	44	37	11.2	1	70	0	1.6	21.0	24444	1629	580	39
12421	10	6	5	44	37	16.0	1	80	0	1.6	18.8	3795	759	67	13

Table A.2 (Continued).

CON#	HWY	D	T	SD	CO	L.M.	S	YR	YRS	THIK	PTR	TOTADT	ADT	TESAL	ESAL
9470	14	6	5	44	56	33.0	1	73	83	1.5	13.5	2593	216	37	3
13064	16	4	5	44	37	8.9	1	81	0	1.3	14.0	2691	672	40	10
11669	16	4	5	44	91	5.7	1	78	0	1.8	15.0	3546	506	51	7
12634	49	3	5	44	37	23.0	1	80	0	1.6	14.0	2541	508	35	7
11769	55	3	5	44	56	40.4	1	79	0	1.5	13.0	1621	270	20	3
12212	55	3	5	44	56	8.8	1	79	0	1.8	13.0	4142	690	50	8
9469	55	3	5	44	45	12.6	1	73	83	1.8	13.0	9097	758	126	10
12338	114	6	5	44	56	9.8	1	80	0	1.5	13.0	1938	387	24	5
10477	114	6	5	44	56	14.6	1	76	82	1.0	19.5	4746	527	96	11
10800	114	6	5	44	56	8.0	1	77	79	2.0	20.3	6776	847	139	17
8092	114	6	5	44	37	7.6	1	69	79	1.6	21.0	31927	1995	759	47
14816	9	1	5	25	27	3.7	1	84	0	1.0	5.5	11897	11897	55	55
4	9	1	5	25	35	5.6	1	68	0	6.9	6.0	12258	721	64	4
4	9	2	5	25	35	5.4	1	68	0	6.9	6.0	12258	721	64	4
10653	13	3	5	25	27	12.4	1	76	83	1.3	8.0	9293	1032	77	9
9400	13	3	5	25	27	8.0	1	73	83	0.7	8.0	17842	1486	151	13
9006	13	3	5	25	27	11.4	1	72	84	1.0	8.0	11247	865	99	8
9006	13	3	5	25	85	6.2	1	72	84	1.0	8.0	12529	963	110	8
9389	13	3	5	25	85	6.2	1	73	0	0.9	7.6	20797	1733	163	14
10046	13	3	5	25	85	22.0	1	75	0	1.4	8.0	19673	1967	167	17
11373	16	4	5	25	9	7.8	1	78	82	1.5	14.0	2912	416	39	6
11509	16	4	5	25	52	12.9	1	78	82	1.5	10.0	3094	442	29	4
12027	16	4	5	25	85	5.0	1	79	82	2.0	8.0	1683	280	12	2
91566	16	4	5	25	85	8.9	1	55	0	1.1	8.0	6275	209	58	2
91565	16	4	5	25	35	4.9	1	55	83	1.0	8.0	9169	305	84	3
14924	18	4	5	25	27	7.2	1	84	0	0.8	7.8	2188	2188	19	19
11	18	4	5	25	27	2.3	1	55	81	1.0	5.5	86305	2876	402	13
11362	105	2	5	25	35	26.7	1	78	0	1.8	10.0	1822	260	17	2
11479	124	6	5	25	52	2.2	1	80	0	2.6	8.8	1839	367	16	3
1	124	6	5	25	85	11.6	1	56	78	1.3	8.0	17596	606	161	6
1	124	6	5	25	85	14.8	1	56	81	1.3	8.0	12357	426	114	4
6879	124	6	5	25	35	7.2	1	67	78	1.0	8.0	8292	460	76	4
12849	20	4	3	41	46	3.9	1	81	0	2.5	13.0	4079	1019	55	14
6342	35	1	3	41	75	7.9	1	64	0	2.3	16.5	60629	2887	1144	54
10536	35	1	3	41	75	5.7	1	76	0	1.0	14.8	10372	1152	159	18
11420	35	1	3	41	46	0.5	1	78	0	2.8	17.4	47113	6730	761	109
12337	35	1	3	41	46	5.9	1	80	0	1.5	15.8	14994	2998	226	45
9087	231	1	3	44	37	6.1	1	53	0	3.0	14.0	32522	1084	521	17
9210	31	1	3	25	52	17.0	1	75	0	3.0	22.0	24145	2414	562	56
9196	31	1	3	25	52	10.6	1	75	0	3.0	22.5	20997	2099	499	50
9210	31	2	3	25	52	16.6	1	75	0	3.0	22.0	24145	2414	562	56

Table A.2 (Continued).

CON#	HWY	D	T	SD	CO	L.M.	S	YR	YRS	THIK	PTR	TOTADT	ADT	TESAL	ESAL
9196	31	2	3	25	52	11.2	1	75	0	3.0	22.5	,20997	2099	499	50
5177	9	1	6	34	48	10.4	1	62	0	1.1	10.0	141806	6165	1412	61
10818	13	3	6	34	30	19.2	1	77	0	0.6	5.5	8212	1026	46	6
10532	13	3	6	34	48	13.0	1	76	0	0.8	6.8	4432	492	31	3
10795	13	3	6	34	29	12.6	1	77	0	0.8	8.5	19341	2417	165	21
12845	26	4	6	34	27	4.7	1	81	83	2.2	8.0	3765	941	31	8
12846	26	4	6	34	27	3.4	1	81	83	2.2	8.0	4315	1078	36	9
10957	26	4	6	34	27	4.1	1	77	83	1.1	8.0	10377	1297	84	10
10957	26	4	6	34	27	5.2	1	77	83	1.1	8.0	5863	732	47	6
11369	38	4	6	34	29	7.2	1	79	0	1.5	6.8	6835	1139	43	7
9674	38	4	6	34	48	4.0	1	74	0	0.9	5.5	11388	1035	67	6
8673	38	4	6	34	48	1.9	1	71	0	1.0	5.5	28572	2040	175	13
11840	38	4	6	34	48	9.0	1	79	0	2.2	5.5	6695	1115	35	6
8579	9	1	6	53	3	2.8	1	71	0	1.5	6.5	18483	1320	134	10
9586	9	1	6	53	3	4.0	1	75	0	3.0	6.5	8444	844	58	6
11299	9	1	6	53	3	8.6	1	78	0	2.0	8.0	12412	1773	94	13
12045	44	5	6	53	41	7.2	1	80	0	1.6	6.0	14891	2978	82	16
9891	46	5	6	53	3	2.4	1	75	0	3.0	5.0	45264	4526	207	21
5	46	5	6	53	3	3.5	1	62	0	1.0	5.0	138640	6027	596	26
10187	46	5	6	53	3	1.7	1	75	0	1.3	5.0	65141	6514	296	30
10666	46	5	6	53	3	4.6	1	76	0	1.0	8.0	30697	3410	255	28
12086	46	5	6	53	3	13.4	1	79	0	2.5	10.3	8744	1457	85	14
8679	46	5	6	53	16	4.6	1	71	0	1.0	5.0	24068	1719	105	8
5724	46	5	6	53	16	14.7	1	63	79	0.9	9.0	24911	1132	257	12
9891	46	4	6	53	3	2.4	1	75	0	3.0	5.0	45264	4526	207	21
10802	135	3	6	53	41	4.4	1	77	0	1.6	11.0	25064	3133	278	35
8906	135	3	6	53	41	9.4	1	72	0	1.3	6.0	31752	2442	208	16
10802	135	3	6	53	41	16.0	1	77	0	1.6	5.9	42514	5314	250	32
13186	252	4	6	53	41	2.6	1	81	0	1.3	6.0	5763	1440	36	9
10667	252	4	6	53	73	4.7	1	77	0	1.8	6.0	4606	575	28	3
10370	61	1	6	63	87	10.9	1	76	0	1.0	9.5	19123	2124	189	21
2	62	4	6	63	82	3.0	1	51	0	1.0	20.8	109472	3649	1951	65
13489	65	1	6	63	82	7.3	1	83	0	1.6	5.0	1597	798	9	5
11386	65	1	6	63	65	0.9	1	78	0	1.0	5.0	3940	562	19	3
9026	65	1	6	63	26	4.9	1	72	0	0.8	13.0	4435	341	63	5
4360	65	1	6	63	26	5.3	1	59	0	0.8	13.0	26132	1005	388	15
10193	69	2	6	63	65	9.0	1	75	0	1.0	5.0	10344	1034	56	6
12095	69	2	6	63	65	13.8	1	79	0	3.0	5.0	9034	1507	42	7
12215	165	2	6	63	65	3.9	1	80	0	3.0	5.0	7622	1524	37	7
13428	165	2	6	63	65	1.9	1	82	0	1.5	5.0	3168	1056	18	6
8683	165	2	6	63	65	10.4	1	71	0	1.5	13.0	8348	596	123	9

Table A.2 (Continued).

CON#	HWY	D	T	SD	CO	L.M.	S	YR	YRS	THIK	PTR	TOTADT	ADT	TESAL	ESAL
6352	168	6	6	63	26	15.4	1	64	0	3.0	13.0	16659	793	246	12
6989	168	6	6	63	26	18.8	1	66	0	1.5	13.0	8947	470	132	7
10544	261	3	6	63	87	4.8	1	76	0	1.0	5.5	51607	5734	258	29
11851	261	3	6	63	87	15.4	1	79	0	1.5	9.5	13755	2292	124	21
10572	25	3	6	13	79	4.0	1	78	0	2.6	10.3	22976	3282	226	33
13171	55	3	6	13	86	20.8	1	81	0	1.6	11.5	2352	588	28	7
13084	55	3	6	13	86	9.0	1	81	0	1.5	12.3	1741	435	22	5
13084	55	3	6	13	4	7.0	1	81	0	1.5	13.0	3174	793	43	11
11048	55	3	6	13	4	20.6	1	77	0	1.5	13.0	3577	447	47	6
0	225	1	6	13	79	2.9	1	56	84	1.5	13.5	14106	486	216	7
8995	225	1	6	13	79	1.1	1	72	84	1.5	13.5	5872	451	87	7
13470	352	5	6	13	4	8.7	1	83	0	2.0	13.0	1461	730	22	11
11901	3	2	6	54	10	13.3	1	79	0	1.8	13.3	6629	1104	81	13
9602	11	2	6	54	31	20.4	1	74	0	1.0	6.5	4543	413	31	3
11380	11	2	6	54	31	9.5	1	78	0	1.8	6.3	2079	297	13	2
12341	60	6	6	54	88	30.2	1	80	0	1.9	13.3	14198	2839	183	37
10478	62	4	6	54	13	15.2	1	76	0	1.3	6.3	3863	429	25	3
14696	62	4	6	54	31	2.1	1	84	0	1.4	6.5	4328	4328	33	33
9022	62	4	6	54	31	14.2	1	72	0	1.0	6.3	14515	1116	100	8
13185	62	4	6	54	10	15.1	1	81	0	0.7	11.5	11774	2943	142	36
11226	64	5	6	54	31	1.0	1	78	0	0.6	6.5	10422	1488	65	9
11226	64	5	6	54	31	4.3	1	78	0	0.6	6.5	16347	2335	102	15
7649	111	1	6	54	31	12.5	1	62	81	1.5	6.5	2684	116	19	1
10053	111	1	6	54	31	10.8	1	75	0	1.5	6.3	11315	1131	75	8
1	111	1	6	54	22	1.3	1	80	0	1.5	3.5	26232	5246	85	17
13286	111	1	6	54	22	2.4	1	82	0	1.5	3.5	18499	6166	54	18
11225	111	1	6	54	22	6.6	1	78	0	2.1	3.5	11846	1692	39	6
11379	160	6	6	54	10	16.8	1	78	83	1.6	11.5	2963	423	33	5
6187	403	3	6	54	10	11.2	1	64	83	1.8	11.9	53207	2533	700	33
4786	462	4	6	54	31	3.0	1	60	79	2.0	8.0	2491	99	22	1
12204	42	6	6	11	11	18.4	1	79	0	1.6	8.0	3006	501	22	4
14922	42	6	6	11	11	15.6	1	84	0	1.7	8.0	325	325	3	3
10357	46	5	6	11	84	7.4	1	76	83	0.5	6.0	18962	2106	105	12
11761	46	5	6	11	60	14.7	1	79	0	2.6	22.0	6284	1047	132	22
12208	59	1	6	11	11	12.1	1	79	0	1.6	16.0	3174	529	46	8
11046	59	1	6	11	11	0.6	1	77	0	1.0	13.6	24940	3117	316	40
10166	59	1	6	11	11	4.1	1	75	83	1.5	14.8	14512	1451	212	21
8873	63	2	6	11	84	8.4	1	72	83	2.8	13.6	42451	3272	515	40
8880	63	2	6	11	83	14.4	1	72	83	3.1	11.8	29152	2242	377	29
6574	63	1	6	11	84	8.4	1	64	83	1.5	12.1	56273	2679	716	34
8880	63	1	6	11	84	14.4	1	72	83	1.5	11.8	29152	2242	377	29

Table A.2 (Continued).

CON#	HWY	D	T	SD	CO	L.M.	S	YR	YRS	THIK	PTR	TOTADT	ADT	TESAL	ESAL
11360	157	2	6	11	28	13.8	1	78	0	1.5	7.8	2573	367	19	3
11659	159	3	6	11	84	23.2	1	79	0	1.5	12.0	4506	751	51	8
8688	246	4	6	11	84	5.8	1	71	84	1.0	12.0	5966	426	81	6
3580	246	4	6	11	84	7.3	1	53	84	0.5	12.0	12340	411	170	6
12205	246	4	6	11	11	6.6	1	79	0	1.8	8.0	2766	461	21	4
12407	246	4	6	11	11	14.8	1	80	0	1.6	7.8	1677	335	13	3
11382	31	1	4	53	3	7.0	1	78	0	0.6	4.5	27539	3934	117	17
11382	31	2	4	53	3	9.0	1	78	0	0.6	4.5	27539	3934	117	17
11068	421	1	4	53	16	3.2	1	77	0	2.0	5.0	21789	2723	102	13
8374	421	1	4	53	16	2.0	1	70	0	1.0	6.8	29253	1950	199	13
5647	150	6	4	54	88	12.8	1	62	0	1.0	15.0	24424	1061	418	18
10537	150	6	4	54	31	6.6	1	76	0	1.3	8.0	17083	1898	142	16
9994	150	6	4	54	31	21.8	1	75	0	1.0	9.8	29223	2922	302	30
10791	1	3	5	24	17	18.2	3	77	82	1.0	15.0	6581	822	104	13
11181	8	5	5	24	17	0.9	3	60	0	1.5	6.5	126242	5049	704	28
12330	9	3	5	24	57	28.4	3	80	84	2.0	23.5	11916	2383	283	57
30283	9	3	5	24	44	1.0	3	73	0	1.0	25.0	45809	3817	1238	103
12330	9	3	5	24	44	2.8	3	80	0	1.6	25.0	17571	3514	452	90
0	427	2	5	24	17	0.5	3	60	0	2.0	15.0	38596	1543	647	26
9791	2	5	5	41	46	1.4	3	81	0	2.6	13.0	8716	2179	117	29
12527	2	5	5	41	46	12.2	3	80	0	2.6	16.5	13220	2644	214	43
11740	2	4	5	41	46	0.4	3	81	0	2.6	13.0	6785	1696	90	23
9791	2	4	5	41	46	1.0	3	81	0	2.6	13.0	7417	1854	99	25
12527	2	4	5	41	46	12.2	3	80	0	2.6	16.5	13220	2644	214	43
11517	10	6	5	44	56	8.0	3	78	0	3.5	19.5	5692	813	107	15
11224	16	4	5	44	56	4.1	3	78	0	1.1	13.0	4599	657	57	8
8375	16	4	5	44	56	4.7	3	70	0	2.7	13.0	8364	557	122	8
10058	16	4	5	44	37	4.2	3	75	0	1.0	14.0	4736	473	70	7
10477	16	4	5	44	37	1.7	3	76	0	2.3	14.0	4741	526	69	8
11520	114	6	5	44	37	1.2	3	78	0	2.6	21.0	9505	1357	198	28
10358	9	1	5	25	27	6.1	3	76	0	2.1	7.4	21934	2437	164	18
10471	9	1	5	25	35	4.7	3	76	0	2.1	27.5	12669	1407	364	40
10258	9	1	5	25	35	6.8	3	77	0	3.0	27.5	5647	705	156	20
10258	9	2	5	25	35	6.8	3	77	0	3.0	27.5	5647	705	156	20
11510	13	3	5	25	85	4.6	3	78	84	0.6	8.0	7153	1021	55	8
11662	13	3	5	25	85	5.8	3	78	0	1.3	6.0	28569	4081	164	23
8572	18	4	5	25	27	2.5	3	71	82	2.0	8.0	24960	1782	225	16
11370	18	4	5	25	27	11.0	3	78	0	1.6	8.0	10854	1550	82	12
5	6	5	3	24	17	0.6	3	68	83	1.3	25.0	49797	2929	1428	84
10470	6	5	3	24	17	6.5	3	76	83	1.3	25.0	23791	2643	623	69
10470	6	5	3	24	17	3.1	3	76	0	1.3	25.0	19329	2147	504	56

Table A.2 (Continued).

CON#	HWY	D	T	SD	CO	L.M.	S	YR	YRS	THIK	PTR	TOTADT	ADT	TESAL	ESAL
13413	20	4	3	24	44	9.7	3	82	0	1.3	25.0	4755	1585	138	46
7038	20	4	3	24	44	11.0	3	66	84	3.0	25.0	30666	1614	878	46
8894	20	4	3	24	76	11.0	3	72	83	2.6	20.5	32863	2527	720	55
9669	20	4	3	24	76	9.4	3	74	84	2.9	22.0	20055	1823	472	43
11898	6	5	3	41	46	11.7	3	79	0	2.0	13.0	14962	2493	185	31
11898	6	5	3	41	46	6.0	3	79	83	2.0	13.0	9017	1502	109	18
11678	20	5	3	41	46	3.0	3	84	0	2.5	17.4	7532	7532	110	110
8565	20	5	3	41	46	2.7	3	71	0	3.0	17.4	86579	6184	1310	94
9989	20	5	3	41	46	1.2	3	75	0	2.0	13.0	33868	3386	468	47
4	20	5	3	41	46	12.0	3	75	0	2.0	13.0	33388	3338	462	46
10365	20	5	3	41	46	11.8	3	76	0	1.6	13.0	20542	2282	277	31
11678	20	4	3	41	46	3.0	3	84	0	2.5	17.4	7532	7532	110	110
8565	20	4	3	41	46	2.7	3	71	0	3.0	17.4	86579	6184	1310	94
9989	20	4	3	41	46	12.0	3	75	0	2.0	17.4	31149	3114	498	50
10365	20	4	3	41	46	11.8	3	76	0	1.6	13.0	20542	2282	277	31
11375	35	1	3	41	46	9.2	3	78	0	1.6	13.0	11735	1676	145	21
11375	35	1	3	41	46	4.6	3	78	0	1.6	17.4	16914	2416	287	41
3319	35	1	3	41	46	8.4	3	51	0	3.5	17.4	54270	1809	810	27
7837	24	6	3	44	56	9.2	3	69	0	2.2	19.5	27838	1739	616	38
7742	24	6	3	44	56	13.0	3	68	0	2.3	19.5	27693	1629	612	36
13421	24	6	3	44	56	20.6	3	82	0	2.0	20.3	4829	1609	113	38
8087	41	1	3	44	56	7.2	3	69	0	2.9	19.5	22923	1432	508	32
8087	41	2	3	44	56	7.0	3	69	0	2.9	19.5	22923	1432	508	32
10058	41	2	3	44	56	16.2	3	75	0	1.2	19.5	13684	1368	282	28
10058	41	2	3	44	56	2.4	3	75	0	1.2	19.5	14762	1476	304	30
13419	231	1	3	44	37	2.8	3	82	0	2.0	14.0	3238	1079	52	17
8095	231	1	3	44	37	4.2	3	69	0	1.0	14.0	19068	1191	300	19
9991	231	1	3	44	37	3.2	3	75	0	1.0	14.0	20330	2033	301	30
11520	231	1	3	44	37	13.2	3	78	0	1.6	14.0	15771	2253	212	30
11108	24	5	3	25	85	8.0	3	78	0	2.6	6.0	10294	1470	59	8
12329	24	5	3	25	85	15.0	3	80	0	2.6	21.2	14479	2895	296	59
11108	24	4	3	25	85	8.0	3	78	0	2.6	6.0	10294	1470	59	8
12329	24	4	3	25	85	15.0	3	80	0	2.6	21.2	16798	3359	344	69
10114	31	1	3	25	52	19.6	3	75	0	3.0	22.0	31239	3123	729	73
10114	31	2	3	25	52	19.6	3	75	0	3.0	22.0	31239	3123	729	73
2	9	1	6	34	48	7.2	3	59	0	1.3	12.0	148686	5718	1537	59
10065	9	1	6	34	48	4.2	3	75	0	1.0	10.8	24301	2430	252	25
9403	9	1	6	34	48	10.0	3	75	84	1.1	8.0	20936	2093	177	18
2	9	2	6	34	48	7.2	3	59	0	1.3	12.0	148686	5718	1537	59
10065	9	2	6	34	48	19.2	3	75	0	1.0	9.0	32240	3224	296	30
11212	13	3	6	34	48	11.8	3	78	0	1.6	5.5	9989	1427	54	8

Table A.2 (Continued).

CON#	HWY	D	T	SD	CO	L.M.	S	YR	YRS	THIK	PTR	TOTADT	ADT	TESAL	ESAL
12416	13	3	6	34	48	6.6	3	73	0	1.1	8.0	8053	671	68	6
11031	28	6	6	34	48	5.4	3	77	0	1.1	8.0	32051	4006	258	32
11513	28	6	6	34	48	26.6	3	78	0	1.3	8.6	14688	2098	120	17
14631	32	5	6	34	29	7.6	3	84	0	3.0	9.0	1292	1292	13	13
12417	32	5	6	34	48	8.4	3	80	0	1.8	9.6	13652	2730	126	25
14370	32	5	6	34	48	2.0	3	71	0	1.0	12.0	41968	2997	440	31
5031	32	5	6	34	48	4.6	3	60	0	0.5	12.0	94085	3763	970	39
13475	109	1	6	34	30	8.8	3	82	0	2.6	11.5	2084	694	28	9
11067	252	4	6	53	41	8.6	3	77	0	1.3	6.0	7380	922	45	6
13189	62	4	6	63	65	6.4	3	81	0	3.0	5.0	5469	1367	28	7
12859	62	4	6	63	82	7.0	3	81	0	3.5	20.8	17638	4409	326	82
12858	62	4	6	63	82	2.8	3	81	0	3.5	20.8	20291	5072	376	94
12858	62	5	6	63	82	3.0	3	81	0	3.5	20.8	20291	5072	376	94
10482	66	4	6	63	82	5.5	3	76	0	2.5	20.8	63761	7084	1219	135
9308	28	6	6	13	86	28.2	3	73	83	1.5	13.0	14180	1181	195	16
5150	62	4	6	54	22	10.1	3	61	0	1.0	15.2	259944	10831	3388	141
9409	64	5	6	54	31	10.7	3	73	0	0.9	6.3	35676	2973	237	20
11065	135	3	6	54	31	24.8	3	77	0	2.0	8.0	16116	2014	130	16
13889	42	6	6	11	84	10.6	3	83	0	2.0	10.2	2450	1225	27	13
11828	46	5	6	11	84	3.4	3	79	0	2.8	12.0	17778	2963	200	33
9667	46	5	6	11	84	9.8	3	74	0	2.4	10.0	13909	1264	149	14
10357	46	4	6	11	84	7.4	3	76	83	0.5	6.0	18962	2106	105	12
11203	63	2	6	11	84	13.8	3	78	84	1.5	10.5	13687	1955	137	20
5	31	1	4	53	3	4.2	3	54	0	1.0	6.0	39750	1325	273	9
10662	31	1	4	53	41	16.8	3	76	0	1.3	6.0	13217	1468	82	9
12045	31	1	4	53	41	23.4	3	80	0	1.0	5.0	19143	3828	93	19
5	31	2	4	53	3	6.2	3	54	0	2.5	6.5	55118	1837	587	20
9683	31	2	4	53	31	4.4	3	74	0	1.0	6.0	39750	1325	273	9
10662	31	2	4	53	41	16.8	3	76	0	1.3	6.0	13217	1468	82	9
12045	31	2	4	53	41	23.2	3	80	0	1.0	5.0	19143	3828	93	19
12425	421	1	4	53	69	9.3	3	80	0	1.7	11.3	7516	1503	82	16
10207	41	1	4	63	82	12.2	3	76	0	4.9	20.8	50399	5599	961	107
10108	41	1	4	63	82	11.2	3	75	0	5.9	5.0	41898	4189	221	22
10109	41	1	4	63	82	10.2	3	76	0	5.5	9.0	34831	3870	326	36
11299	41	1	4	63	26	8.8	3	76	0	4.8	13.0	34743	3860	469	52
11621	41	1	4	63	26	16.0	3	79	0	5.6	13.0	16421	2736	199	33
10207	41	2	4	63	82	11.8	3	76	0	4.9	20.8	50399	5599	961	107
10108	41	2	4	63	82	11.4	3	75	0	5.9	5.0	41898	4189	221	22
10109	41	2	4	63	82	9.0	3	76	0	5.5	9.0	34831	3870	326	36
11299	41	2	4	63	26	10.0	3	76	0	4.8	13.0	34743	3860	469	52
11621	41	2	4	63	26	16.0	3	79	0	5.6	13.0	16421	2736	199	33

Table A.2 (Continued).

CON#	HWY	D	T	SD	CO	L.M.	S	YR	YRS	THIK	PTR	TOTADT	ADT	TESAL	ESAL
13410	52	5	4	13	79	12.2	3	82	0	1.6	13.0	6086	2028	92	31
7433	52	4	4	13	4	6.8	3	67	0	2.0	17.5	17058	947	341	19
7433	52	4	4	13	4	15.4	3	67	0	2.0	17.5	15105	839	303	17
4759	52	4	4	13	4	6.4	3	59	0	2.5	17.5	23827	916	478	18
13410	52	4	4	13	79	12.2	3	82	0	1.6	13.0	6055	2018	91	30
8471	52	4	4	13	79	2.6	3	73	0	2.5	7.5	50229	4185	340	28
5569	41	2	4	13	86	12.6	3	62	0	3.3	13.0	15841	688	237	10
9428	41	2	4	13	86	4.0	3	76	0	3.0	15.3	9976	1108	159	18
8066	40	4	4	11	84	9.0	3	69	0	2.1	9.3	26298	1643	245	15
14047	40	4	4	11	84	4.6	3	83	0	1.6	6.5	6012	3006	33	16
13019	40	4	4	11	84	9.0	3	81	0	1.0	6.5	13876	3469	81	20
8556	40	4	4	11	84	10.4	3	71	0	1.0	11.5	49689	3549	636	46
5411	40	4	4	11	11	11.2	3	82	0	2.1	7.6	4745	1581	38	13
12630	40	4	4	11	11	14.0	3	80	0	2.2	7.3	10980	2196	77	15
8066	40	5	4	11	84	9.0	3	69	0	2.1	9.3	26298	1643	245	15
14047	40	5	4	11	84	4.6	3	83	0	1.6	6.5	6012	3006	33	16
13019	40	5	4	11	84	8.8	3	81	0	1.0	6.5	13876	3469	81	20
8556	40	5	4	11	84	10.2	3	71	0	1.0	11.5	49689	3549	636	46
5411	40	5	4	11	11	11.2	3	81	0	2.1	7.6	6754	1688	50	13
12630	40	5	4	11	11	14.0	3	80	0	2.2	7.3	10980	2196	77	15
12581	41	1	4	11	77	6.4	3	80	0	3.8	11.5	18953	3790	213	43
12582	41	1	4	11	84	14.2	3	82	0	3.7	11.5	13147	4382	175	58
13168	41	1	4	11	84	1.8	3	82	0	2.8	13.6	26670	8890	304	101
3	41	1	4	11	84	5.0	3	53	0	1.5	13.6	183516	6117	2113	71
8407	41	1	4	11	84	13.4	3	70	0	2.3	13.6	26861	1790	316	21
12581	41	2	4	11	77	6.4	3	80	0	3.8	11.5	19432	3868	218	44
12582	41	2	4	11	84	14.0	3	82	0	3.7	11.5	13147	4382	175	58
8407	41	2	4	11	84	11.4	3	70	0	2.3	13.1	26924	1794	376	25
14704	41	2	4	11	61	13.6	3	84	0	3.0	11.8	1440	1440	20	20
14630	150	4	4	11	84	7.6	3	84	0	2.8	11.5	663	663	9	9
8318	150	4	4	11	84	5.3	3	70	0	2.3	13.6	40771	2718	480	32
4927	9	3	5	24	44	11.4	2	61	0	9.0	25.0	41152	1714	1655	69
5157	2	5	5	41	46	7.0	2	62	0	9.0	14.8	46129	2005	1009	44
5176	2	5	5	41	46	7.0	2	62	0	9.0	13.0	40601	1765	872	38
5157	2	4	5	41	46	7.0	2	62	0	9.0	14.8	46129	2005	1009	44
5176	2	4	5	41	46	7.0	2	62	0	9.0	13.0	40601	1765	872	36
3	9	1	5	25	35	11.6	2	68	0	9.0	27.5	11259	662	514	30
3	9	2	5	25	35	11.6	2	68	0	9.0	27.5	11259	662	514	30
9061	18	4	5	25	27	3.6	2	75	0	10.0	7.5	17033	1703	142	14
7544	6	5	3	24	57	11.0	2	68	0	9.0	23.5	39220	2307	1525	90
5464	20	5	3	41	46	1.2	2	63	0	10.0	13.0	17971	816	384	17

Table A.2 (Continued).

CON#	HWY	D	T	SD	CO	L.M.	S	YR	YRS	THIK	PTR	TOTADT	ADT	TESAL	ESAL
4303	30	5	3	41	46	15.2	2	59	77	9.0	13.0	74575	2868	1595	61
4401	30	5	3	41	46	16.8	2	60	77	9.0	14.8	71687	2867	1747	70
4424	30	5	3	41	75	9.8	2	59	0	9.0	16.5	75554	2905	2053	79
4303	30	4	3	41	46	15.6	2	59	77	9.0	13.0	74575	2868	1595	61
4401	30	4	3	41	46	17.0	2	60	77	9.0	14.8	71687	2867	1747	70
4424	30	4	3	41	75	9.0	2	59	0	9.0	16.5	75554	2905	2053	79
5	35	1	3	41	46	2.0	2	55	0	9.0	17.4	43229	1440	935	31
3567	41	1	3	44	56	11.4	2	53	0	9.0	19.5	38389	1279	1230	41
3721	41	1	3	44	56	9.8	2	54	0	9.0	19.5	35217	1173	1128	38
5524	41	1	3	44	56	16.0	2	62	0	9.0	19.5	28704	1248	917	40
5919	41	1	3	44	56	13.4	2	63	0	9.0	19.5	29132	1324	927	42
3797	41	1	3	44	56	10.6	2	54	0	9.0	19.5	43449	1448	1383	46
6	41	2	3	44	56	2.6	2	53	0	9.0	19.5	38370	1279	1229	41
3721	41	2	3	44	56	11.2	2	54	0	9.0	19.5	35217	1173	1128	38
5919	41	2	3	44	56	1.8	2	63	0	9.0	19.5	28182	1281	900	41
5919	41	2	3	44	56	7.4	2	63	0	9.0	19.5	29237	1328	930	42
3797	41	2	3	44	56	10.6	2	54	0	9.0	19.5	43387	1443	1379	46
10298	24	5	3	25	52	1.8	2	77	0	10.0	22.0	11982	1497	389	49
10303	24	5	3	25	52	12.6	2	77	0	10.0	6.0	11855	1481	98	12
10300	24	5	3	25	52	15.4	2	77	0	10.0	23.5	11445	1430	397	50
10298	24	4	3	25	52	1.8	2	77	0	10.0	22.0	11982	1497	389	49
10303	24	4	3	25	52	12.6	2	77	0	10.0	6.0	11855	1481	98	12
10300	24	4	3	25	52	15.4	2	77	0	10.0	23.5	11445	1430	397	50
4	32	5	6	34	48	1.7	2	61	0	9.0	12.0	86291	3595	1296	54
6214	46	5	6	53	7	4.2	2	65	0	8.0	8.0	52306	2615	687	34
5090	46	5	6	53	7	5.1	2	62	0	8.0	8.0	47082	2047	619	27
4714	46	5	6	53	3	6.9	2	60	0	9.0	8.0	92611	3704	1210	48
7934	61	1	6	63	87	8.7	2	71	0	8.0	9.5	16140	1152	250	18
0	62	4	6	63	65	2.4	2	69	0	10.0	20.8	45337	2833	1195	75
10233	62	4	6	63	65	10.2	2	76	0	10.0	5.0	20564	2284	157	17
10234	62	4	6	63	65	11.6	2	76	0	10.0	8.2	24389	2709	298	33
3750	62	4	6	63	82	1.8	2	57	0	9.0	20.8	142996	5107	3712	133
7697	62	5	6	63	65	2.6	2	69	0	9.0	20.8	45337	2833	1195	75
10233	62	5	6	63	65	10.8	2	76	0	10.0	5.0	20612	2290	159	18
8878	62	5	6	63	65	4.8	2	74	0	9.0	5.0	27732	2521	218	20
10234	62	5	6	63	65	4.2	2	76	0	10.0	5.0	26526	2947	202	22
8807	62	5	6	63	82	6.8	2	72	0	9.0	20.8	49334	3794	1338	103
3750	62	5	6	63	82	3.2	2	57	0	9.0	20.8	138608	4950	3592	128
7625	66	4	6	63	65	8.4	2	69	0	7.0	5.0	21392	1337	175	11
7689	66	4	6	63	82	5.2	2	69	0	7.0	20.8	29951	1871	777	49
5202	66	4	6	63	82	4.4	2	62	0	9.0	20.8	121660	5289	3162	137

Table A.2 (Continued).

CON#	HWY	D	T	SD	CO	L.M.	S	YR	YRS	THIK	PTR	TOTADT	ADT	TESAL	ESAL
5460	66	4	6	63	82	2.4	2	65	0	7.0	20.8	155041	7752	4045	202
1	66	4	6	63	87	6.2	2	57	0	9.0	15.2	102476	3659	2246	81
7625	66	5	6	63	65	8.4	2	70	0	7.0	5.0	20320	1354	166	11
7689	66	5	6	63	82	5.4	2	69	0	7.0	20.8	37991	2374	1000	63
5202	66	5	6	63	82	4.4	2	62	0	9.0	20.8	121660	5289	3162	137
5460	66	5	6	63	82	2.4	2	65	0	7.0	20.8	155041	7752	4045	202
10319	26	6	6	13	79	3.8	2	77	0	10.0	7.0	64025	8003	610	76
10674	63	1	6	13	86	8.0	2	77	0	10.0	13.0	10498	1312	201	25
10495	63	1	6	13	86	9.6	2	76	0	10.0	13.0	12216	1357	243	27
10494	63	1	6	13	86	11.2	2	77	0	10.0	13.0	9005	1125	173	22
9874	63	1	6	13	86	3.8	2	76	0	10.0	13.0	9887	1098	197	22
10674	63	2	6	13	86	6.8	2	77	0	10.0	13.0	10379	1297	199	25
10495	63	2	6	13	86	9.6	2	76	0	10.0	13.0	12216	1357	243	27
10494	63	2	6	13	86	9.2	2	77	0	10.0	13.0	9005	1125	173	22
9874	63	2	6	13	86	5.8	2	76	0	10.0	13.0	9887	1098	197	22
4723	3	2	6	54	10	2.4	2	61	0	10.0	15.2	56808	2367	1093	46
4715	64	5	6	54	13	3.2	2	61	78	8.0	6.8	26008	1083	289	12
4715	64	5	6	54	31	2.5	2	61	79	8.0	6.5	44629	1859	479	20
7218	135	3	6	54	31	6.6	2	67	0	8.0	8.0	15814	878	208	12
7879	135	3	6	54	31	13.4	2	70	0	8.0	8.0	16999	1133	223	15
8222	135	3	6	54	31	12.0	2	73	0	8.0	8.0	29671	2472	370	31
3788	59	1	6	11	11	7.0	2	59	0	8.0	16.0	41978	1614	1103	42
2	63	2	6	11	84	3.5	2	62	0	7.0	13.6	245478	10672	4182	182
4	31	1	4	53	3	6.2	2	54	0	9.0	6.5	55118	1837	587	20
8650	41	1	4	63	82	4.8	2	73	0	9.0	20.8	82694	6891	2271	189
8313	41	1	4	63	82	4.0	2	73	0	9.0	20.8	87631	7301	2406	201
8650	41	2	4	63	82	5.0	2	73	0	9.0	20.8	82694	6891	2271	189
8313	41	2	4	63	82	3.8	2	73	0	9.0	20.8	87631	7301	2406	201
6959	52	5	4	13	4	4.8	2	66	0	9.0	17.5	16925	890	487	26
5044	52	5	4	13	4	5.0	2	61	0	9.0	17.5	16223	675	466	19
6958	52	5	4	13	4	14.6	2	67	0	9.0	17.5	13950	775	401	22
3786	52	5	4	13	4	5.4	2	59	0	9.0	17.5	20726	797	597	23
3408	52	5	4	13	4	5.8	2	52	0	9.0	17.5	27065	902	780	26
4	52	5	4	13	4	9.4	2	53	0	9.0	15.3	27810	927	699	23
9893	52	5	4	13	79	4.4	2	77	0	9.0	7.5	28565	3570	293	37
8471	52	5	4	13	79	3.0	2	73	0	9.0	7.5	50229	4185	498	41
8347	52	5	4	13	79	2.6	2	72	0	9.0	7.5	65847	5065	645	50
7635	52	5	4	13	79	3.8	2	70	0	9.0	7.5	76525	5101	732	49
5044	52	4	4	13	4	2.6	2	61	0	9.0	17.5	20876	869	605	25
3786	52	4	4	13	4	5.2	2	56	0	9.0	17.5	15976	550	457	16
1	52	4	4	13	4	9.4	2	53	0	9.0	15.3	26566	885	667	22

Table A.2 (Continued).

CON#	HWY	D	T	SD	CO	L.M.	S	YR	YRS	THIK	PTR	TOTADT	ADT	TESAL	ESAL
9893	52	4	4	13	79	4.4	2	77	0	9.0	7.5	28565	3570	293	37
8347	52	4	4	13	79	2.6	2	72	0	9.0	7.5	65847	5065	645	50
7635	52	4	4	13	79	3.8	2	70	0	9.0	7.5	76525	5101	732	49
9569	41	1	4	13	86	17.4	2	75	0	10.0	13.0	7605	760	154	15
9428	41	1	4	13	86	11.4	2	76	0	10.0	15.3	9644	1071	225	25
8182	41	1	4	13	4	17.2	2	71	0	8.0	17.5	15566	1111	448	32
9569	41	2	4	13	86	17.8	2	75	0	10.0	13.0	8214	821	165	16
9569	41	2	4	13	86	2.2	2	76	0	10.0	13.0	8681	964	172	19
9428	41	2	4	13	4	5.2	2	76	0	10.0	17.5	10336	1148	277	31
9908	41	2	4	13	4	16.6	2	76	0	9.0	17.5	10326	1147	277	31
6912	150	6	4	54	22	28.4	2	67	0	9.0	11.5	80488	4471	1503	84
4	41	1	4	11	84	1.0	2	53	0	9.0	13.6	127806	4260	2161	72
13636	41	1	4	11	84	0.8	2	51	0	9.0	13.6	155751	5191	2636	88
4	41	1	4	11	84	3.4	2	51	0	9.0	13.6	163998	5466	2773	92
2	41	2	4	11	84	4.8	2	53	0	9.0	13.6	198600	6620	3211	107
13636	41	1	4	11	84	1.0	2	51	0	9.0	13.6	187558	6251	3171	106
2	41	2	4	11	84	2.0	2	51	0	9.0	13.6	135413	4513	2294	76

Appendix B

Some Statistical Results

Table B.1 Correlation Matrices for Statistical Analysis of Change in Roughness for Interstate Pavements which Received Patching (P).

a) Overlaid Pavements

	LOG(ΔRN)	PATCH	AGE	ESAL	ΣESAL	R
LOG(ΔRN)	1.00000	-0.35523	0.00508	0.31200	0.24552	0.60305
PATCH	-0.35523	1.00000	0.60356	0.60844	0.72571	0.19314
AGE	0.00508	0.60356	1.00000	0.36327	0.68652	0.45108
ESAL	0.31200	0.60844	0.36327	1.00000	0.91967	0.43538
ΣESAL	0.24552	0.72571	0.68652	0.91967	1.00000	0.52249
R	0.60305	0.19314	0.45108	0.43538	0.52249	1.00000

b) Rigid Pavements

	LOG(ΔRN)	PATCH	AGE	ESAL	ΣESAL	R
LOG(ΔRN)	1.00000	-0.03099	-0.02400	0.13236	0.13031	0.24988
PATCH	-0.03099	1.00000	0.26582	-0.03714	0.06314	-0.23591
AGE	-0.02400	0.26582	1.00000	-0.10516	0.16050	-0.58000
ESAL	0.13236	-0.03714	-0.10516	1.00000	0.95845	-0.07480
ΣESAL	0.13031	0.06314	0.16050	0.95845	1.00000	-0.26459
R	0.24988	-0.23591	-0.58000	-0.07480	-0.26459	1.00000

Table B.2 Correlation Matrices for Statistical Analysis of Change in Roughness for Interstate Pavements which Received Patching and Joint and Crack Sealing (PS).

a) Overlaid Pavements

	LOG(ΔRN)	LOG(PS)	LOG(AGE)	LOG(ESAL)	LOG(ΣESAL)	R
LOG(ΔRN)	1.00000	-0.74542	-0.27739	0.39426	-0.00326	0.69002
LOG(PS)	-0.74542	1.00000	-0.22651	-0.56646	-0.40135	-0.28792
LOG(AGE)	-0.27739	-0.22651	1.00000	0.64044	0.93832	-0.25732
LOG(ESAL)	0.39426	-0.56646	0.64044	1.00000	0.86648	0.54799
LOG(ESAL)	-0.00326	-0.40135	0.93832	0.86648	1.00000	0.07983
R	0.69002	-0.28792	-0.25732	0.54799	0.07983	1.00000

b) Rigid Pavements

	LOG(ΔRN)	LOG(PS)	LOG(AGE)	LOG(ESAL)	LOG(ΣESAL)	R
LOG(ΔRN)	1.00000	-0.46823	0.17636	-0.49130	-0.42629	0.15779
LOG(PS)	-0.46823	1.00000	0.03961	0.10107	0.11683	-0.12116
LOG(AGE)	0.17636	0.03961	1.00000	-0.22181	0.17553	-0.40510
LOG(ESAL)	-0.49130	0.10107	-0.22181	1.00000	0.92101	-0.44225
LOG(ΣESAL)	-0.42629	0.11683	0.17553	0.92101	1.00000	-0.60824
R	0.15779	-0.12116	-0.40510	-0.44225	-0.60824	1.00000

Table B.3 Correlation Matrices for Statistical Analysis of Change in Roughness for OSH Pavements which Received Patching (P).

a) Flexible Pavements

	LOG(ΔRN)	PATCH	AGE	ESAL	ΣESAL	R
LOG(ΔRN)	1.00000	-0.04462	0.13911	-0.09886	-0.13373	0.01293
PATCH	-0.04462	1.00000	0.20221	0.17205	0.15084	-0.12088
AGE	0.13911	0.20221	1.00000	-0.12763	0.33212	-0.26675
ESAL	-0.09886	0.17205	-0.12763	1.00000	0.74210	-0.11266
ΣESAL	-0.13373	0.15084	0.33212	0.74210	1.00000	-0.12106
R	0.01293	-0.12088	-0.26675	-0.11266	-0.12106	1.00000

b) Overlaid Pavements

	LOG(ΔRN)	PATCH	AGE	ESAL	ΣESAL	R
LOG(ΔRN)	1.00000	-0.37349	-0.23565	0.01886	-0.19510	-0.04737
PATCH	-0.37349	1.00000	0.35844	0.23582	0.49709	-0.21109
AGE	-0.23565	0.35844	1.00000	-0.02886	0.60429	0.00667
ESAL	0.01886	0.23582	-0.02886	1.00000	0.70322	-0.30515
ΣESAL	-0.19510	0.49709	0.60429	0.70322	1.00000	-0.26748
R	-0.04737	-0.21109	0.00667	-0.30515	-0.26748	1.00000

c) Rigid Pavements

	LOG(ΔRN)	PATCH	AGE	ESAL	ΣESAL	R
LOG(ΔRN)	1.00000	-0.23297	-0.04572	-0.28608	-0.15086	-0.31014
PATCH	-0.23297	1.00000	0.23091	0.06319	0.22621	0.20357
AGE	-0.04572	0.23091	1.00000	-0.15537	0.32715	0.01378
ESAL	-0.28608	0.06319	-0.15537	1.00000	0.82068	0.14984
ΣESAL	-0.15086	0.22621	0.32715	0.82068	1.00000	0.06626
R	-0.31014	0.20357	0.01378	0.14984	0.06626	1.00000

Table B.4 Correlation Matrices for Statistical Analysis of Change in Roughness for OSH Pavements which Received Patching and Joint and Crack Sealing (PS).

a) Flexible Pavements

	LOG(ΔRN)	LOG(PS)	LOG(AGE)	LOG(ESAL)	LOG(ΣESAL)	R
LOG(ΔRN)	1.00000	-0.49731	-0.02529	-0.17450	-0.14940	-0.07884
LOG(PS)	-0.49731	1.00000	0.15384	0.03820	0.11773	0.26277
LOG(AGE)	-0.02529	0.15384	1.00000	-0.07310	0.59367	0.18368
LOG(ESAL)	-0.17450	0.03820	-0.07310	1.00000	0.75781	-0.09268
LOG(ΣESAL)	-0.14940	0.11773	0.59367	0.75781	1.00000	0.02125
R	-0.07884	0.26277	0.18368	-0.09268	0.02125	1.00000

b) Overlaid Pavements

	LOG(ΔRN)	LOG(PS)	LOG(AGE)	LOG(ESAL)	LOG(ΣESAL)	R
LOG(ΔRN)	1.00000	-0.15343	0.17843	0.18165	0.28298	-0.11721
LOG(PS)	-0.15343	1.00000	0.33939	0.27502	0.42120	-0.25778
LOG(AGE)	0.17843	0.33939	1.00000	0.03589	0.72116	0.00885
LOG(ESAL)	0.18165	0.27502	0.03589	1.00000	0.70711	-0.24477
LOG(ΣESAL)	0.28298	0.42120	0.72116	0.70711	1.00000	-0.15646
R	-0.11721	-0.25778	0.00885	-0.24477	-0.15646	1.00000

c) Rigid Pavements

	LOG(ΔRN)	LOG(PS)	LOG(AGE)	LOG(ESAL)	LOG(ΣESAL)	R
LOG(ΔRN)	1.00000	0.01322	0.61446	-0.03366	0.28316	-0.46308
LOG(PS)	0.01322	1.00000	0.23400	0.17505	0.23244	-0.02995
LOG(AGE)	0.61446	0.23400	1.00000	0.40432	0.78016	-0.42921
LOG(ESAL)	-0.03366	0.17505	0.40432	1.00000	0.88732	0.03155
LOG(ΣESAL)	0.28316	0.23244	0.78016	0.88732	1.00000	-0.18785
R	-0.46308	-0.02995	-0.42921	0.03155	-0.18785	1.00000

Table B.5 Correlation Matrices for Statistical Analysis of Change in Roughness for OSH Pavements which Received All Patching and Sealing (APS).

a) Flexible Pavements

	LOG(ΔRN)	APS	AGE	ESAL	ΣESAL	R
LOG(ΔRN)	1.00000	-0.52505	0.10910	-0.54775	-0.22464	-0.24642
APS	-0.52505	1.00000	-0.24804	0.04783	-0.12186	-0.30134
AGE	0.10910	-0.24804	1.00000	-0.05968	0.39204	-0.40214
ESAL	-0.54775	0.04783	-0.05968	1.00000	0.80511	0.35425
ΣESAL	-0.22464	-0.12186	0.39204	0.80511	1.00000	0.11202
R	-0.24642	-0.30134	-0.40214	0.35425	0.11202	1.00000

b) Overlaid Pavements

	LOG(ΔRN)	APS	AGE	ESAL	ΣESAL	R
LOG(ΔRN)	1.00000	-0.38356	0.06931	-0.39080	-0.27617	-0.54820
APS	-0.38356	1.00000	0.12875	0.10418	0.12488	-0.29877
AGE	0.06931	0.12875	1.00000	0.40810	0.55933	-0.16990
ESAL	-0.39080	0.10418	0.40810	1.00000	0.97693	0.22845
ΣESAL	-0.27617	0.12488	0.55933	0.97693	1.00000	0.13314
R	-0.54820	-0.29877	-0.16990	0.22845	0.13314	1.00000

Table B.6 Statistical Characteristics of OSH Patching (P) Effect Models.

Criterion	Flexible	Rigid	Overlaid
Number of Observations	78	44	47
Coeff. of Determination (R^2)	0.09	0.30	0.18
Adjusted Coeff. (adj. R^2)	0.04	0.23	0.10
Linearity Test			
F-Value	1.40	3.29	1.74
α Level	0.236	0.015	0.147
Significance Test for Coefficients			
P			
F-Value	0.73	3.11	4.52
α Level	0.396	0.086	0.04
Age			
F-Value	5.72	4.92	0.01
α Level	0.019	0.033	0.915
ESAL			
F-Value	2.35	9.03	0.41
α Level	0.13	0.005	0.524
ΣESAL			
F-Value	4.54	6.42	0.23
α Level	0.037	0.016	0.635
Region			
F-Value	0.49	1.31	0.57
α Level	0.485	0.26	0.456

Table B.7 Statistical Characteristics of OSH Patching and Joint and Crack Sealing (PS) Effect Models.

Criterion	Flexible	Rigid	Overlaid
Number of Observations	44	43	57
Coeff. of Determination (R^2)	0.28	0.53	0.25
Adjusted Coeff. (adj. R^2)	0.21	0.49	0.19
Linearity Test			
F-Value	2.90	8.38	3.31
α Level	0.026	0	0.012
Significance Test for Coefficients			
Log_{10}(PS)			
F-Value	11.40	1.67	6.43
α Level	0.002	0.204	0.014
Log_{10}(Age)			
F-Value	0.09	2.73	3.37
α Level	0.769	0.107	0.072
Log_{10}(ESAL)			
F-Value	0.13	1.93	3.67
α Level	0.718	0.173	0.061
Log_{10}(ΣESAL)			
F-Value	0.10	2.11	5.26
α Level	0.757	0.155	0.026
Region			
F-Value	0.13	0.27	1.63
α Level	0.725	0.607	0.208

Table B.8 Statistical Characteristics of OSH Patching (P) Effect Models by Region.

Criterion	Northern Region			Southern Region		
	Flexible	Rigid	Overlaid	Flexible	Rigid	Overlaid
Number of Observstions	37	15	27	41	29	20
Coeff. of Determination (R^2)	0.14	0.31	0.35	0.15	0.31	0.13
Adjusted Coeff. (adj. R^2)	0.06	0.11	0.26	0.08	0.22	-0.03
Linearity Test						
F-Value	1.30	1.11	2.92	1.62	2.66	0.57
α Level	0.291	0.404	0.044	0.191	0.057	0.689
Significance Test for Coefficients						
P						
F-Value	0.68	4.14	7.49	0.91	1.67	0.03
α Level	0.416	0.069	0.012	0.346	0.209	0.855
Age						
F-Value	3.92	0.25	1.08	0.09	5.70	0.74
α Level	0.056	0.63	0.31	0.767	0.025	0.404
ESAL						
F-Value	2.92	0.03	2.04	2.66	8.88	0.21
α Level	0.097	0.863	0.167	0.112	0.007	0.652
ΣESAL						
F-Value	4.44	0.43	1.40	1.10	5.82	0.13
α Level	0.043	0.526	0.249	0.301	0.024	0.726

Table B.9 Statistical Characteristics of OSH Patching and Joint and Crack Sealing (PS) Effect Models by Region.

Criterion	Northern Region			Southern Region		
	Flexible	Rigid	Overlaid	Flexible	Rigid	Overlaid
Number of Observations	19	15	19	25	28	38
Coeff. of Determination (R^2)	0.31	0.74	0.51	0.43	0.25	0.25
Adjuated Coeff. (adj. R^2)	0.17	0.68	0.41	0.35	0.15	0.19
Linearity Test						
F-Value	1.59	7.25	3.64	3.84	1.94	2.77
α Level	0.23	0.005	0.031	0.018	0.138	0.043
Significance Test for Coefficients						
Log_{10}(PS)						
F-Value	3.22	1.17	2.67	13.98	1.08	3.94
α Level	0.094	0.31	0.124	0.001	0.309	0.056
Log_{10}(Age)						
F-Value	1.71	3.69	4.34	3.37	0.44	4.32
α Level	0.212	0.084	0.056	0.082	0.513	0.046
Log_{10}(ESAL)						
F-Value	1.83	2.75	4.31	3.29	0.33	4.35
α level	0.197	0.128	0.056	0.085	0.570	0.045
Log_{10}(ΣESAL)						
F-Value	1.69	2.63	4.18	3.31	0.36	5.79
α Level	0.215	0.136	0.060	0.084	0.556	0.022

Table B.10 R^2 Values of the Linear Relationships between Pavement Roughness and Pavement Age Under Different Traffic-Maintenance Levels Combinations.

Highway Class	Pavement Type	Level Combination	Northern Region		Southern Region	
			Patching and Jt. & Crack Sealing	Patching	Patching and Jt. & Crack Sealing	Patching
Interstate	Rigid	LL	0.00	*	0.08	0.04
		LH	0.89	*	0.78	0.13
		HL	0.00	*	0.35	**
		HH	0.10	0.15	**	0.13
	Overlaid	LL	**	0.58	*	0.80
		LH	*	*	0.94	*
		HL	*	**	**	**
		HH	**	**	*	0.97
Other State Highways	Flexible	LL	0.25	0.55	0.24	0.24
		LH	0.75	0.02	**	0.001
		HL	0.25	0.18	0.32	0.01
		HH	**	0.12	0.32	0.89
	Rigid	LL	0.96	0.02	0.23	0.72
		LH	**	**	0.10	0.97
		HL	0.81	0.76	0.84	0.06
		HH	**	0.69	0.14	0.82
	Overlaid	LL	**	0.23	0.56	0.54
		LH	0.54	**	0.01	**
		HL	0.44	0.01	0.28	0.15
		HH	0.93	0.41	0.64	**

Table B.11 R^2 Values of the Nonlinear Relationships between Pavement Roughness and Pavement Age Under Different Traffic-Maintenance Levels Combinations.

Highway Class	Pavement Type	Level Combination	Northern Region		Southern Region	
			Patching and Jt. & Crack Sealing	Patching	Patching and Jt. & Crack Sealing	Patching
Interstate	Rigid	LL	0.00	*	0.08	0.02
		LH	0.89	*	0.70	0.09
		HL	0.00	*	0.30	**
		HH	0.09	0.14	**	0.07
	Overlaid	LL	**	0.66	*	0.87
		LH	*	*	0.96	*
		HL	*	**	**	**
		HH	**	**	*	0.98
Other State Highways	Flexible	LL	0.20	0.54	0.23	0.20
		LH	0.57	0.01	**	0.001
		HL	0.15	0.25	0.28	0.03
		HH	**	0.28	0.33	0.87
	Rigid	LL	0.95	0.05	0.21	0.53
		LH	**	**	0.13	0.95
		HL	0.76	0.67	0.76	0.09
		HH	**	0.57	0.07	0.77
	Overlaid	LL	**	0.28	0.68	0.72
		LH	0.61	**	0.03	**
		HL	0.52	0.02	0.26	0.23
		HH	0.93	0.42	0.72	**

* No observations were available

** Less than three observations were available

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